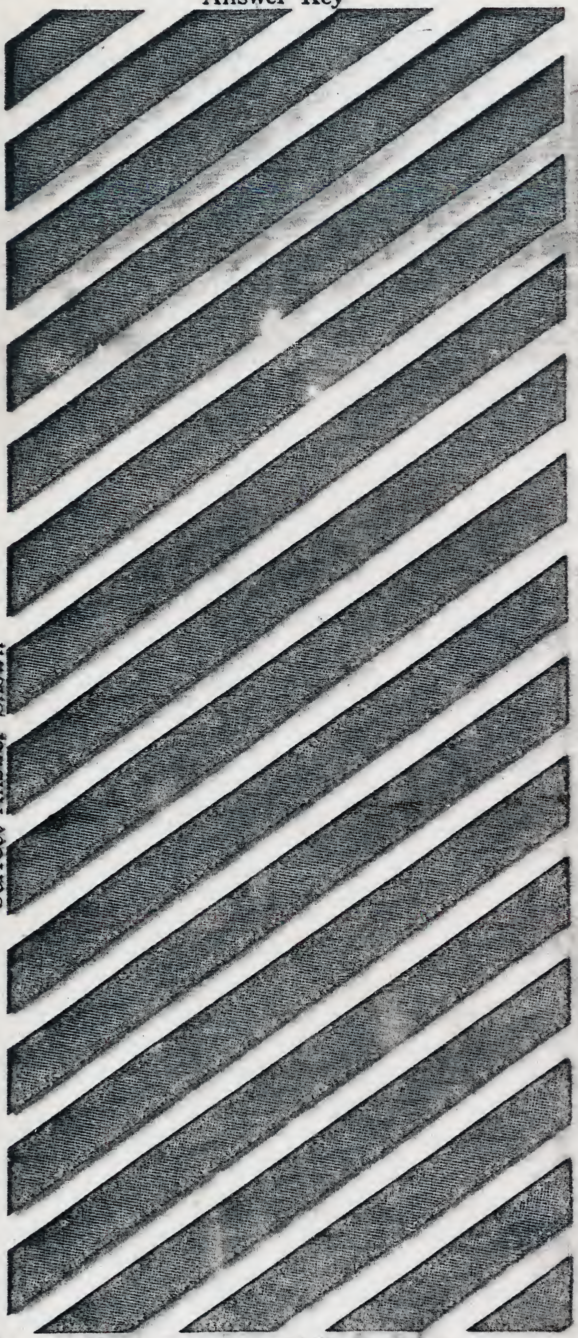
DORSETT EDUCATIONAL SYSTEMS, INC.
Answer Key



Correct Answer Shown

Align Bottom and Left Edge

1. Which is the lightest particle?
   - ◯ proton
   - ◯ electron
   - ◯ neutron
   - ◯ molecule

2. Which is an insulator?
   - ◯ aluminum foil
   - ◯ copper wires
   - ◯ paper wrapping
   - ◯ silver wires

3. Who determined what the force was between two charged objects?
   - ◯ Ampere
   - ◯ Coulomb
   - ◯ Pascal
   - ◯ Avogadro

4. What is voltage?
   - ◯ electron flow
   - ◯ neutron pressure
   - ◯ electrical pressure
   - ◯ proton force

5. What are atoms with too many or too few electrons called?
   - ◯ pions
   - ◯ ions
   - ◯ neutrinos
   - ◯ muons

6. Which is a measure of electron flow?
   - ◯ power
   - ◯ conductance
   - ◯ current
   - ◯ voltage

7. Object A has more excess electrons than Object B. What is A's polarity relative to B?
   - ◯ non-polar
   - ◯ negative
   - ◯ equal
   - ◯ positive

8. Which way do electrons flow?
   - ◯ positive to negative
   - ◯ no flow
   - ◯ negative to positive
   - ◯ to neutrons

1. How many watts of power are used when a resistance has 120 V across it and draws 15 amps?
   - ◯ 1600
   - ◯ 2400
   - ◯ 1800
   - ◯ 1000

2. A 15 V battery is supplying 75 watts of power. How much current is flowing?
   - ◯ 110 amps
   - ◯ 5 amps
   - ◯ 1135 amps
   - ◯ 10 amps

3. What is the electric force called?
   - ◯ current
   - ◯ power
   - ◯ voltage
   - ◯ resistance

4. How many amps flow through an 8-ohm load from a 24-volt supply?
   - ◯ 112
   - ◯ 3
   - ◯ .33
   - ◯ 25

5. What is the unit of current?
   - ◯ watts
   - ◯ ohms
   - ◯ amps
   - ◯ volts

6. If a circuit draws 65 amps at 220 volts, how much power is used?
   - ◯ 150 watts
   - ◯ 14.3 kw
   - ◯ 321 watts
   - ◯ 3.8 kw

7. Which has an effect on a wire's resistance?
   - ◯ geometric angle
   - ◯ weight
   - ◯ total length
   - ◯ gravity

8. Besides a voltage source and a load, what else must be present for current to flow?
   - ◯ heat
   - ◯ conductors
   - ◯ light
   - ◯ insulators

1. How are batteries connected to increase the total voltage, but not the current?
   - sideways
   - diagonally
   - series
   - parallel

2. How are batteries connected to increase the current supply, but not the voltage?
   - sideways
   - parallel
   - series
   - diagonally

3. Which type of battery is usually rechargeable?
   - primary
   - tertiary
   - secondary
   - quarterly

4. Since there are 3600 seconds in an hour, how many joules are available from a 12 V, 60 ampere-hour battery?
   - 1000 kilojoules
   - 2592 kilojoules
   - 3400 kilojoules
   - 4328 kilojoules

5. In a battery, what do the electrodes do?
   - nothing
   - act as conductors
   - insulate the cell
   - recharge the hydrogen

6. What is the electrolyte's function in a battery?
   - provides electric current
   - provides chemical action with electrodes
   - regenerates hydrogen
   - develops power

7. What is the "nominal" voltage of a battery?
   - the total working load voltage
   - the approximate no-load voltage
   - 5 V
   - the discharged voltage

1. What color band in which position represents a resistor value between one and 10Ω ?
   - silver, first
   - red, second
   - gold, third
   - green, fourth

2. What color band in which position indicates a resistor value of less than 1 ohm?
   - black, second
   - silver, third
   - orange, third
   - blue, second

3. What is the resistor color code for 9?
   - gray
   - red
   - white
   - black

4. What resistor is represented by green, blue, yellow, and silver?
   - 500Ω , 5% tolerance
   - 6500Ω
   - 560,000Ω , 10% tolerance
   - 56Ω

5. Which color stands for a 5% tolerance?
   - purple
   - gold
   - silver
   - green

6. Which band indicates the number of zeroes?
   - first
   - second
   - third
   - fourth

7. What tolerance is indicated when there is no fourth band?
   - 15%
   - 20%
   - 25%
   - 30%

8. What color sequence represents 6300Ω ?
   - blue, green, orange
   - red, orange, black
   - blue, orange, red
   - blue, brown, red

1. A load is drawing 640 watts of power from 120 V source. What is the current?
   - ○ 7.2 amps
   - ○ 8.1 amps
   - ○ 5.3 amps
   - ○ 9 amps

2. In a DC circuit with a constant resistance, how does the current behave with an increase in voltage?
   - ○ no change
   - ○ increases
   - ○ discharges
   - ○ decreases

3. Which is Ohm's Law?
   - ○ $I = ER$
   - ○ $R = EI$
   - ○ $E = IR$
   - ○ $P = \frac{I}{E}$

4. Fifteen amps is drawn from a 180 V source. What is the resistance?
   - ○ 10 ohms
   - ○ 12 ohms
   - ○ 20 ohms
   - ○ 25 ohms

5. Which describes how current is found?
   - ○ $R = \frac{E}{I}$
   - ○ $I = \frac{R}{E}$
   - ○ $E = IR$
   - ○ $I = \frac{E}{R}$

6. At 160 V and 5 amps, what is the resistance?
   - ○ .625 ohm
   - ○ 32 ohms
   - ○ 1.3 ohms
   - ○ 110 ohms

7. Which is a formula for power?
   - ○ $P = \frac{R}{I}$
   - ○ $P = IR^2$
   - ○ $P = IR$
   - ○ $P = I^2R$

8. If the current is 6 milliamps and the resistance is 12 K-ohms, what is the voltage?
   - ○ 7.2 V
   - ○ 2 V
   - ○ 72 V
   - ○ .5 V

1. Whose law states that the algebraic sum of the voltages in a circuit is zero?
   - ◯ Kirchhoff's Voltage Law
   - ◯ Kirchhoff's Current Law
   - ◯ Ohm's Law
   - ◯ Coulomb's Law

2. What are the IR drops across these resistors?

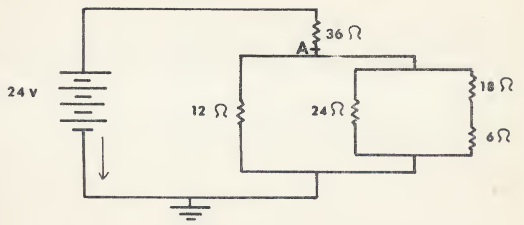
   ◯ 8 V, 4 V   ◯ 7 V, 5 V   ◯ 6 V, 3 V

3. Which law states that the sum of the voltage rises in a circuit must equal the sum of the voltage drops?
   - ◯ Kirchhoff's Resistance Law
   - ◯ Kirchhoff's Current Law
   - ◯ Kirchhoff's Voltage Law
   - ◯ Kirchhoff's Power Law

4. What is the current through a 12 Ω and a 6 Ω resistor connected in series to a 12 V supply?
   - ◯ .2 amp   ◯ .5 amp
   - ◯ .667 amp   ◯ 1 amp

5. If the voltage equation for a circuit is 18 - 6(I) - 2(I) - 10(I) = 0, what is I?
   - ◯ .5 amp   ◯ 1 amp
   - ◯ 1.5 amps   ◯ 2.0 amps

6. If I_1 flows through a 6 Ω resistance and I_2 flows through a 12 Ω resistance, and the voltage is 150 V, what is I?
   - ◯ 12 amps   ◯ 37.5 amps
   - ◯ 18.4 amps   ◯ 6.67 amps



1. What is the current through the top resistor?
   - ◯ 1.3 amps
   - ◯ 1.2 amps
   - ◯ .57 amp
   - ◯ 2.4 amps

2. What is the combined resistance of the far right branch?
   - ◯ 30 ohms
   - ◯ 24 ohms
   - ◯ 24 ohms
   - ◯ 10 ohms

3. What is the single equivalent resistance in the circuit?
   - ◯ 21 ohms
   - ◯ 30 ohms
   - ◯ 42 ohms
   - ◯ 56 ohms

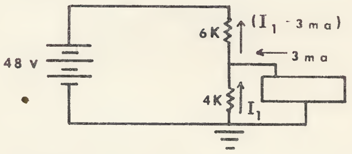
4. What is the combined resistance of the center parallel section?
   - ◯ 4 ohms
   - ◯ 6 ohms
   - ◯ 4.5 ohms
   - ◯ 5 ohms

5. What is the current through the equivalent resistor?
   - ◯ .3 amp
   - ◯ .91 amp
   - ◯ .57 amp
   - ◯ 1.3 amps

6. What is the voltage at A if the combined center resistance is 6 ohms and I = .57 amp?
   - ◯ 14 V
   - ◯ 3.4 V
   - ◯ 34 V
   - ◯ 0 V

1. In a Wheatstone Bridge, where is the unknown resistor located?
   - ◯ in same series branch as rheostat
   - ◯ position corresponding to rheostat in parallel leg
   - ◯ series position with R_2
   - ◯ in resonance with R_3

2. In the ratio bridge, where is the unknown resistor located?
   - ◯ in same series branch as rheostat
   - ◯ series position with R_2
   - ◯ in resonance with R_3
   - ◯ position corresponding to rheostat in parallel leg



Use this circuit to answer the following questions.

3. In a ratio bridge, R_1 = 6 K-ohms, R_2 = 4 K-ohms, and R_4 = 10 K-ohms. What is R_3?
   - ◯ 10 K-ohms
   - ◯ 25 K-ohms
   - ◯ 20 K-ohms
   - ◯ 15 K-ohms

4. What is the current I_1 through the circuit above?
   - ◯ .5 amp
   - ◯ 3 ma
   - ◯ 2 amps
   - ◯ 1 ma

5. What are the IR drops across the resistors?
   - ◯ 24 V, 24 V
   - ◯ 30 V, 18 V
   - ◯ 36 V, 12 V
   - ◯ 34 V, 14 V

6. In the circuit, what is the power used in the 6 K resistor?
   - ◯ 216 watts
   - ◯ .216 watt
   - ◯ 2.16 kw
   - ◯ 2.16 watts

1. The force between two magnets is 100 dynes. If the distance is tripled, what happens to the force?
   - ◯ force is tripled
   - ◯ force decreased to $\frac{1}{9}$ of original
   - ◯ force increased nine times
   - ◯ force decreased by $\frac{1}{3}$

2. What is the magnetic permeability of air?
   - ◯ .2
   - ◯ .5
   - ◯ 1
   - ◯ 10

3. Which way does the magnetic field point in a wire with current flowing downward?
   - ◯ diagonally to the right
   - ◯ diagonally to the left
   - ◯ clockwise, looking down
   - ◯ counterclockwise, looking down

4. In which direction is the attractive force between two wires with current flowing in opposite directions?
   - ◯ toward each other
   - ◯ north of each
   - ◯ repelling each other
   - ◯ no force exists

5. Which is the formula for magnetic flux?
   - ◯ $\Phi = \frac{H}{R}$
   - ◯ $R = \Phi H$
   - ◯ $E = \frac{\Phi}{L}$
   - ◯ $\mu = \frac{A}{L}$

6. What magnetic quality generates heat in transformers?
   - ◯ R-curve parameters
   - ◯ Gilbert's force
   - ◯ hysteresis
   - ◯ conductance reversed

7. What are the molecular sized magnets which make up magnetic materials?
   - ◯ demesnes
   - ◯ domains
   - ◯ demains
   - ◯ ferrules

1. How is current generated in a transformer?
   - ◯ conduction
   - ◯ induction
   - ◯ AC rectification
   - ◯ electrostatic attraction

2. What is the formula for the voltage induced in an alternator?
   - ◯ $V = .02\Phi fn$
   - ◯ $f = \frac{n}{.2\Phi}$
   - ◯ $.2n\,\Phi = nV$
   - ◯ $\frac{.02}{f} = n\Phi$

3. If there are four pairs of magnetic poles and the loop rotates at 60 RPS, what is the frequency of the voltage?
   - ◯ 60 Hz
   - ◯ 240 Hz
   - ◯ 90 Hz
   - ◯ 180 Hz

4. Which wave form does a typical AC voltage produce?
   - ◯ a parabola
   - ◯ a circle
   - ◯ a sine curve
   - ◯ a hyperbola

5. In a rotating loop alternator, when is the generated voltage at its maximum?
   - ◯ when the loop is parallel to the flux lines
   - ◯ when the loop is at a 45° angle to the flux lines
   - ◯ when the loop is at 90° to the flux lines
   - ◯ when the loop is at 15° to the flux lines

6. What is the frequency of 6 pairs of poles turning at 3600 RPM?
   - ◯ 60 Hz
   - ◯ 240 Hz
   - ◯ 360 Hz
   - ◯ 720 Hz

7. How many alternations in one period of an AC sine wave?
   - ◯ 1
   - ◯ 2
   - ◯ 3
   - ◯ 4

(Assume sine waves for these questions.)

1. How many maximums are reached in 1 second in a 60 Hz wave?
   - ○ 30
   - ○ 60
   - ○ 120
   - ○ 90

2. Which is a formula for instantaneous voltage?
   - ○ $e = (E_m)(\sin \omega t)$
   - ○ $E_m \sin t = \frac{1}{\Phi}$
   - ○ $e = 1.414\ R$
   - ○ $e = \frac{E_m}{E}$

3. What is e when $E_m = 160$ V and $\sin \omega t = .15$?
   - ○ 50 V
   - ○ 100 V
   - ○ 24 V
   - ○ 150 V

4. What is the resultant voltage if $E_1 = 30$ V and $E_2 = 40$ V and they are 90° out of phase?
   - ○ 20 V
   - ○ 50 V
   - ○ 70 V
   - ○ 95 V

5. If E = 141 V, what is E_m?
   - ○ 100 V
   - ○ 120 V
   - ○ 200 V
   - ○ 282 V

6. If the peak-to-peak voltage is 400 V, what is the RMS voltage?
   - ○ 150 V
   - ○ 141 V
   - ○ 200 V
   - ○ 400 V

7. If the RMS voltage equals 150 V, what is E_{avg}?
   - ○ 110 V
   - ○ 120 V
   - ○ 135 V
   - ○ 150 V

8. If two waves reach their maximum and minimum values simultaneously, what is their relationship?
   - ○ 45° out of phase
   - ○ in phase
   - ○ 90° out of phase
   - ○ 180° out of phase

1. If $L = 15$ h and the current is changing at a rate of .8 ampere every .2 seconds, what is e?
   - ◯ $3\frac{1}{4}$ V
   - ◯ 12 V
   - ◯ 60 V
   - ◯ 120 V

2. Which is the formula for the RL time constant?
   - ◯ $\frac{L}{R}$
   - ◯ $\frac{R}{L} \times 60$
   - ◯ RL
   - ◯ $k\left(\frac{R_1 L_1}{q}\right)$

3. An inductor opposes changes in ________________.
   - ◯ impedance
   - ◯ voltage
   - ◯ current
   - ◯ power

4. If $k = 1$, $L_1 = 12$ h, and $L_2 = 12\ \mu$ h, what is the mutual inductance?
   - ◯ 1.2 h
   - ◯ .012 h
   - ◯ 120 h
   - ◯ 0 h

5. What is the formula for the voltage induced by an inductor?
   - ◯ $e = -L\frac{\Delta i}{\Delta t}$
   - ◯ $e = \frac{I(\Delta t)}{L(\Delta i)}$
   - ◯ $L = \Delta i \frac{e}{\Delta t}$
   - ◯ $\frac{\Delta i}{\Delta t} = -Le$

6. If the coupling coefficient K between two inductors is .3, and $L_1 = 64$ mh, and $L_2 = .4$ h, what is the mutual inductance?
   - ◯ 300 h
   - ◯ .09 h
   - ◯ 48 mh
   - ◯ 10 μ h

7. If $L_1 = 24$ mh, $L_2 = 6$ mh, and $K = .5$, and they are in series opposing each other, what is the total inductance?
   - ◯ 42 mh
   - ◯ 18 mh
   - ◯ 30 mh
   - ◯ 12 mh

1. What is the phase angle between the induced voltage and the current in an inductor?
   - ◯ 15°
   - ◯ 90°
   - ◯ 120°
   - ◯ 180°

2. What is the formula for X_L?
   - ◯ $2\pi fL$
   - ◯ $\frac{1}{2\pi fC}$
   - ◯ $\frac{L}{2\pi f}$
   - ◯ $\frac{2\pi}{fL}$

3. If f = .120 Hz and L = 30 mh, what is X_L?
   - ◯ 12 ohms
   - ◯ 15 ohms
   - ◯ 23 ohms
   - ◯ 30 ohms

4. What is the power factor of a circuit with a 30° degree phase angle?
   - ◯ 30%
   - ◯ 86.6%
   - ◯ 50%
   - ◯ 70.7%

5. What is the impedance if R = 20 Ω and X_L = 15 Ω ?
   - ◯ 10 ohms
   - ◯ 15 ohms
   - ◯ 25 ohms
   - ◯ 20 ohms

6. If the impedance is 50 Ω and the resistance is 30 Ω, what is X_L?
   - ◯ 56 ohms
   - ◯ 40 ohms
   - ◯ 69 ohms
   - ◯ 90 ohms

7. What is the impedance if R = 60 Ω and X_L = 80 Ω ?
   - ◯ 150 ohms
   - ◯ 200 ohms
   - ◯ 100 ohms
   - ◯ 250 ohms

8. If the total series impedance is 80 Ω and the phase angle is 60°, what is R?
   - ◯ 40 ohms
   - ◯ 69 ohms
   - ◯ 56 ohms
   - ◯ 90 ohms

1. What is the charge stored in 60 μf capacitor at 120 V?
   - ◯ 3600 coulombs
   - ◯ 7200 coulombs
   - ◯ 6000 coulombs
   - ◯ 9600 coulombs

2. If k = 3, A = 14 sq. in., and d = 7 in., what is C?
   - ◯ 1350 f
   - ◯ 1350 mf
   - ◯ 1.35 pf
   - ◯ 135 μf

3. What is the formula for capacitance? (d, A in inches)
   - ◯ $C = .225\frac{kA}{d}$
   - ◯ $C = \frac{.225k}{dA}$
   - ◯ $C = .225\,k\frac{d}{A}$
   - ◯ $C = .225\,QV$

4. If k = 1, A = 5 sq. in., d = 5, what is C?
   - ◯ .225 μf
   - ◯ 225 f
   - ◯ .225 pf
   - ◯ 1 μf

5. What is the capacitance of 3 capacitors of .01 microfarad, .25 microfarad, and 50,000 picofarad connected in series?
   - ◯ 40 pf
   - ◯ 125 μf
   - ◯ .008 μf
   - ◯ .08 pf

6. What is the time constant for 12 μf capacitor in series with 15 Ω resistor?
   - ◯ 1.25 seconds
   - ◯ 180 micro-seconds
   - ◯ .8 seconds
   - ◯ 60 seconds

7. What is the total capacitance when an 18 microfarad, a 12 microfarad, and a 40 microfarad capacitor are connected in parallel?
   - ◯ 20 μf
   - ◯ 70 μf
   - ◯ 150 μf
   - ◯ 216 μf

1. When is capacitor current at its maximum?
   - ◯ when it reverses
   - ◯ when power increases
   - ◯ when voltage is at minimum
   - ◯ when impedance is high

2. What is the current-voltage relationship in a capacitor?
   - ◯ I is the same vector as E
   - ◯ E leads I
   - ◯ I leads E
   - ◯ $I = \frac{E}{P}$

3. What is the capacitive reactance when f = 530 Hz and C = 3 μf?
   - ◯ 15 ohms
   - ◯ 125 ohms
   - ◯ 100 ohms
   - ◯ 300 ohms

4. What is the ratio for the reactive "quality," "Q"?
   - ◯ $\frac{\text{reactance}}{\text{resistance}}$
   - ◯ $\frac{\text{power}}{\text{resistance}}$
   - ◯ $\frac{\text{impedance}}{\text{current}}$
   - ◯ $\frac{\text{resistance}}{\text{reactance}}$

5. What is X_c when f = 60 Hz and C = 1325 μf?
   - ◯ 2.5 ohms
   - ◯ 82 ohms
   - ◯ 1.93 ohms
   - ◯ 100 ohms

6. What is the power when E = 150 V, I = 3.5 amps, and the phase angle is 45°?
   - ◯ 143.4 watts
   - ◯ 371.175 watts
   - ◯ 421.63 watts
   - ◯ 500 watts

7. What is the total impedance in a circuit when the resistance equals 60 ohms and the inductive reactance equals 90 ohms?
   - ◯ 93 ohms
   - ◯ 108.2 ohms
   - ◯ 100 ohms
   - ◯ 105 ohms

1. What is the current-voltage phase relationship in an inductor?
   - ◯ I leads E by 90°.
   - ◯ I lags E.
   - ◯ I and E are equal.
   - ◯ I and E are the same vector.

2. What is characteristic of parallel RCL circuits?
   - ◯ high voltage
   - ◯ no resonance frequency
   - ◯ high currents
   - ◯ small Q

3. What is the power factor when E = 100 V, I = 10 amps, and the phase angle is 90°?
   - ◯ .125
   - ◯ 0
   - ◯ .5
   - ◯ .625

4. In what component does the current lead the voltage?
   - ◯ inductor
   - ◯ resistor
   - ◯ capacitor
   - ◯ alternator

5. What is the effective Z when $R = 30\,\Omega$, $X_L = 50\,\Omega$, and $X_c = 10\,\Omega$ and they are in series?
   - ◯ 10 ohms
   - ◯ 50 ohms
   - ◯ 25 ohms
   - ◯ 100 ohms

6. What is f_{res} when L = 5h and C = 5 μ f?
   - ◯ 40 Hz
   - ◯ 60 Hz
   - ◯ 32 Hz
   - ◯ 90 Hz

7. What is the phase angle when $X_c = 100\,\Omega$ and $R = 100\,\Omega$?
   - ◯ 15°
   - ◯ 45°
   - ◯ 30°
   - ◯ 60°

8. What is Z when $X_L = 650\,\Omega$ and $X_c = 600\,\Omega$?
   - ◯ $50\,\Omega$, capacitive
   - ◯ $1250\,\Omega$, reactive
   - ◯ $50\,\Omega$, inductive
   - ◯ $1250\,\Omega$, inductive

Electrons and Electricity

1. Electricity and the concepts associated with it are so important to our lives today that we can hardly think of anything that is not related to it. All matter in the universe, the earth, minerals, and elements, is made up of tiny particles called molecules, which are in turn made up of smaller particles called atoms, which finally are made of protons, neutrons, and electrons, the tiniest of all. Protons and electrons have electrical charges. What is matter composed of? (earth and water) (tiny particles) (solids and gases)

2. Correct. They are too small to see even with a microscope like this, but we know that all gases, liquids, and solids are made up of these particles in different arrangements. The particles have different weight and electrical charges. The proton always has a unit weight and a unit positive electric charge; the neutron has a unit weight but no charge; and the electron has a very much lighter weight and a unit negative charge. Which particle has the positive charge? (proton) (neutron) (electron)

3. Yes. The protons and neutrons are thought of as the center core or nucleus of each atom, and the lighter, negatively-charged electrons are in orbit around them, much like the earth and planets are in orbit around the sun. What is the electric charge on the electrons? (positive) (neutral) (negative)

4. Protons, neutrons, and electrons go together to form the atom. Elements are composed of specific atoms which give them individual chemical properties. When elements are combined, they form other chemical groupings called molecules. Most matter that we deal with is formed from molecules.

5. In some materials or elements, the orbiting electrons freely leave their "atom" and will move along together like water in a pipe; these materials are called conductors. These loosely-bound electrons in the outer orbits are called "valence electrons." Metallic materials, such as copper, silver, and aluminum, let their electrons move freely and are used as conductors of electricity. Which of these is a conductor? (copper power line wires) (rubber gloves) (carpeting)

6. Yes. In many materials, the orbiting electrons are held tightly to their "atom" and do not move freely. These non-conducting materials, such as glass, paper, most plastics, rubber and wood, are called insulators. We sometimes use insulators to confine electrons to a path we choose---such as when we use rubber as an insulator around copper wire. Which of these is an insulator? (copper power line wires) (rubber gloves) (aluminum foil)

7. Good. Sometimes the motion of rubbing on an insulator such as a plastic comb will force electrons to leave their atoms. Since the electrons can't flow easily, they become crowded together and cause the insulator to be charged with nonmoving or static electricity. We're all familiar with electrostatic sparks caused by our walking on a carpet, and we can see static electricity at work when we see small bits of paper being attracted to a comb. What does electrostatic mean? (moving electricity) (nonmoving electricity)

8. Right. This illustration shows two kinds of electrostatically-charged objects—negatively-charged and positively-charged. If two objects are electrostatically-charged so that one has many free electrons, we say that object is more negatively-charged than an object with fewer electrons. Thus, the object with fewer electrons is said to be more positively-charged. We call these negative and positive charges polarities. What is the polarity of the object with many free electrons? (negative polarity) (positive polarity)

9. If in an insulator we find a static or nonmoving electrical charge, what might we find happening in a good conductor? (electrons moving) (electrons not moving)

10. Yes. When two objects are charged with the same static electric polarity, such as both negatively-charged or both positively-charged, they will repel, or push away from each other, even before they touch. What do you think objects would do when they have different charges? (repel each other) (attract each other)

11. Right. When one object is positive and the other is negative, they attract each other. Push the button under the object that has the negative polarity. (A) (B)

12. Right, because it has many electrons. Which of these objects has the positive charge? (A) (B)

13. Yes, object "A" has fewer electrons and, therefore, a positive charge. Which of these electrically-charged objects would most attract each other? (A and B) (A and C) (B and C)

14. Gold, silver, copper, and aluminum have loosely-bound electrons and so are good conductors. Silver conducts current well, but copper is less expensive. Aluminum is not quite as good a conductor as either, but is light in weight and not expensive.

15. Normally, an atom has the same number of electrons and protons. This gives the atom a neutral charge. An atom with an extra electron, or a missing electron, has a net electrical charge, and it is called an "ion." A positive ion has a missing electron; a negative ion has gained an extra electron.

16. The atomic structure of certain elements, like germanium and silicon, permit only a slight movement of electrons. As a result, materials made of these elements will conduct current, but not very easily. These materials are called semiconductors.

17. When there is a substantial excess or deficiency of electrons remaining on an insulated object,

there is an electrostatic or "static" electric charge created. This excess or deficiency causes an "electrostatic force" which can be measured in volts. For example, an electrostatic charge can be set up by rubbing a hard rubber rod or comb with hair or fur.

18. The attraction and repulsion of charges can be shown by paper balls suspended by threads. When charged alike, they swing apart; when charged unlike, they swing together. We can calculate the attracting or repelling force by using "Coulomb's Law," discovered by French scientist Charles Coulomb. This law states that the attractive or repelling force of two or more charged bodies is proportional to the product of their charges, and inversely proportional to the square of their distance apart.

19. Electrons are far too small to consider individually. For convenience, we employ a unit of charge which represents a large number of electrons. This unit of electric charge is the coulomb. One coulomb of charge means that a material has 6.24×10^{18} too many or too few electrons.

20. We said electrons will move through a conductor if the ends of the conductor are connected to objects with unlike polarities. The crowded electrons in the negatively-charged object produce an electrical force or pressure which moves the electrons through a conductor very much like water pressure moves water through a pipe. When there is electron flow, this electrical pressure is called electromotive force. You probably recognize it by its more common name—voltage. Voltage is another name for what? (electromotive force) (water pressure) (magnetic field)

21. Yes. If this force or voltage is great enough, it can even cause electrons to move through an insulator. For instance, a lightning bolt is a very large spark caused by a static electric charge jumping through air, which is a good insulator.

22. Batteries also produce voltage, but in much smaller proportions than do lightning discharges. Batteries are made of certain chemicals that contain many free electrons. These many electrons provide the pressure or voltage that is needed to move the electrons through a conductor that is connected to the battery. What word below best describes voltage? (flow) (pressure) (chemical)

23. The electrons from a battery always move through a conductor in the same direction. They move from the terminal with many electrons, to the terminal with few electrons. How could you say this? [electrons flow from (-) to (+)] [electrons flow from (+) to (-)]

24. Whenever voltage is used to cause electrons to move through a conductor, the movement or flow of electrons is called current. Current is a measure of the number of electrons moving past a point on a conductor in a given time. Voltage is the pressure that causes electrons to move. The movement of electrons is called what? (current) (electromotive force) (magnetic field)

25. Yes. Voltage and current are basic elements of electricity. The voltage supplies the pressure to move the current of electrons, and the electron movement provides energy to perform whatever work is needed, like running an electric motor, or lighting a light bulb.

26. Before going to the next program, let's review some of the concepts covered in this lesson. What are the three smallest particles known to make up all matter? (protons, neutrons, electrons) (molecules, atoms, bits) (sand, salt, water)

27. Yes. Protons have a positive charge, and neutrons have no charge. What electrical charge do electrons have? [quick charge] [(-) charge] [(±) charge]

28. Correct, a negative charge. Some materials allow electrons to move freely through them. What is the general name given to these materials? (conductors) (molecules) (insulators)

29. Yes. Materials that resist free movement of electrons are called what? (conductors) (insulators) (particles)

30. Good. The "shock" that we get in wintertime whenever we touch something after walking across a carpet is caused by what kind of electrical charge? (static charge) (magnetic charge) (free charge)

31. Yes. Whenever electrons become bunched together, what is the polarity of the charge? (positive) (neutral) (negative)

32. Right, a negative charge or polarity. When two objects have the same charge polarity and are brought near each other, what do they do? (attract) (repel) (drop)

33. Which way do electrons flow? [from (-) to (+) polarity] [from (+) to (-) polarity]

34. Yes, that's correct. The pressure that is used to make electrons move through a conductor has two names. What are they? (current, gravity) (resistance, conductance) (electromotive force, voltage)

35. Yes. What name is given to the measure of the number of electrons flowing past a point during a given time? (voltage) (resistance) (current)

36. The electrons in an atom which are rotating in orbit around the nucleus are said to have their electrical attraction to it exactly balanced by their centrifugal force. What particles are mainly in the nucleus? (electrons and molecules) (ions and pions) (neutrons and protons)

37. Whose law states that the force between two charged objects is proportional to the product of their charges and inversely proportional to the square of their distance apart? (Ampere's Law) (Coulomb's Law) (Boyle's Law)

38. What are two basic elements of electricity? (insulators, water) (voltage, current) (conductors, ground)

BASIC ELECTRICITY Reference Folder Pe 2

Electric Power, Voltage, Current and Resistance

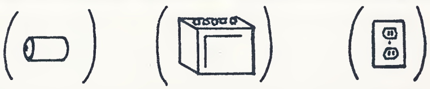
1. Electrical power is the term that indicates the rate of work that is being accomplished by moving electrons. The unit of electrical power is the watt, named after the nineteenth century scientist, James Watt. You can get electric power from a flashlight battery, an automobile battery, or from an electric outlet in your home. Any source of voltage and current is a source of electric power. Electric power comes from the flow of electrons, the tiny, negative particles present in all the material of the universe.

2. In the first program, you learned that electrons flow well in most metals, which are called conductors, but poorly in wood, paper, glass or plastic, which are insulators. Which of these is an insulator? (rubber gloves) (aluminum foil) (copper wire)

3. Yes. The flow of water in a river is called the "current." We call the flow of electrons in a conductor an "electric current." This current flow may come from a battery and flow through conductors to a lamp; then the current flows back to the source. The unit of current is the ampere, which is the flow of 6.24×10^{18} electrons, or one coulomb, past a point in one second. What is electric current? (power) (water) (flow of electrons)

4. We know that water or air will flow only when there is pressure or force to make it flow. The electromotive force that causes electrons to flow is also called voltage. This force from a flashlight cell is only 1½ volts; a new car battery has 12 volts, and your house electric outlets are 120 volts. Like the force behind a water faucet or tire valve, the voltage is there, whether or not there is flow. What is the name of this electric force? (current) (voltage) (electrons)

5. Yes. Voltage may be considered the electric force between one point which has an accumulation of electrons with negative charges and another point which has excess positive charges, or a deficiency of negative electrons, which is the same thing. Which of these voltage sources would have the highest electric force?



6. There are many ways to generate voltage. In addition to producing electrostatic voltage through friction, electromotive force or voltage which can produce power is also generated by batteries, by rotating electromagnetic generators and alternators, by chemical fuel cells, and by photoelectric solar cells.

7. Electric current flows and power is transmitted only when there is a conducting circuit to some electrical load which converts the electric energy to some other form like heat, light, sound, or mechanical energy. If there is no conducting circuit, the voltage may exist, but

there is no current flowing and no power transmitted.

8. You know that the water in our piped water systems makes a complete circuit from the reservoir to our homes, out the drain, and eventually back to the reservoir as rain. Electrical circuits must be complete, too, for current to flow. There must be a voltage source, a load, and conductors to carry the electric current from the source to and from the load. Current flows only when the circuit includes all three things. What are conductors used for? (to stop the source) (to insulate the load) (to carry the current)

9. That's right. Different loads take different amounts of current from the supply. The current is measured in amperes, or amps for short. Automobile lamp bulbs are often marked 2 amps or 3 amps, meaning 2 amperes or 3 amperes of current will flow through them when they are connected to the car's battery. What is measured in amperes? (electrical pressure) (current flow) (loads)

10. That's correct. Now you have learned that electric current is the flow of "electrons," that this electric current is measured in amperes,and that it comes from a source of electric force, which is measured in volts. You have also learned that the current is carried by metal conductors. What must be in the box at the left of the picture? (voltage source) (insulator) (load)

11. Yes. This electric force, which tends to cause electron flow or current,is called voltage or electromotive force (EMf) and sometimes it's called "potential" or potential difference between two points. What causes this voltage? (An electric power source accumulates electrons at one point, is deficient at other.) (Molecules are oriented toward the axis of the lines of influence.)

12. The value of the volt, which is the unit of voltage, EMf, or potential, was selected by Alessandro Volta from a battery cell he used. A volt is defined as the potential which will cause one ampere of electric current to flow through one ohm of electrical resistance, or which provides one watt of electric power to such a load. Most of our present cells provide 1½ or 2 volts each.

13. Now let's consider the term watt, the unit of power. Light bulbs, for example, are rated in watts. 25, 50, and 100 watts are some typical values. The more watts of power used by a lamp, the more light it gives. A light bulb marked "100 watts" uses 100 watts of electric power. Other electric appliances may use more or fewer watts of power; some, like air conditioners, use several thousand watts. Watts are units for measuring what? (voltage) (power) (current)

14. Good. There is a definite relationship between amps, volts, and power, in watts. To find watts, multiply volts times amps, or shortened, $W = V \times A$. A 6-volt bulb, with 4 amps of current flowing through it, uses 24 watts; a car head lamp which draws 3 amps from its 12-volt supply uses 36 watts. How many watts are used by a 10-volt lamp drawing 4 amps? (14 watts) (2.5 watts) (40 watts)

15. Yes. If a 60-watt light bulb lights a boat cabin, it draws 5 amps from the boat's 12-volt

battery. That is, 5 amps multiplied by 12 volts gives 60 watts. At home, the electric supply is 120 volts; a 60-watt light bulb, here, uses ½ amp. The lights are just as bright, and each uses 60 watts, but should you exchange the bulbs? (yes) (no)

16. No, because lamp bulbs are made to use power from specific voltage supplies, and the 12-volt bulb would burn out at 120 volts. Some lamps or appliances that have the same power ratings in watts may be designed for connection to different voltages. A cigarette lighter for a 1950 Ford draws 8 amps from the car's 6-volt battery. A 1975 Pontiac lighter draws 4 amps from its 12-volt battery. But both use 48 watts, the product of volts × amps. The Pontiac's headlights draw 10 amperes current from its 12-volt supply. How many watts do they use? (22 watts) (120 watts) (12 watts)

17. Good, 120 watts; volts × amps. An air conditioner that draws 9.1 amps from 220 volts would use about 2,000 watts or 2 kilowatts; we use kilo to mean "times one thousand." 5,000 watts would be 5 kilowatts. If all the loads in your entire home drew 50 amps at 120 volts, how many kilowatts of power were used? (6) (6,000) (170)

18. Yes, 6 kilowatts. Another basic element of electrical theory is resistance. If we had a water faucet turned on full, a lot of water would flow out; if we turn the faucet partly off, the water flow would be limited or resisted, and less water would come out. We say the faucet offers resistance to the flow of water.

19. Remember in our discussion of conductors and insulators we said that some materials, like metals, allow electric current to flow freely, and some materials allow no current flow at all. Inbetween those two extremes is a wide range of materials that allow only some current to flow—that is, they offer some resistance to full current flow. What would happen to current flow if we passed it through a material which had a high resistance? (less current flow) (no change) (more current flow)

20. Yes, high resistance allows less current to flow. Georg Ohm, in a simple electric rule called "Ohm's Law," established one ohm as a unit of resistance which would limit the flow from a one-volt supply to one ampere. That is, if a load of one-ohm resistance is connected to a one-volt source, one amp of current will flow through the load. The Bureau of Standards keeps a reference one-ohm resistor made of mercury in a tube. If the supply is 12 volts, one ohm will let 12 amps flow. Or two ohms would let only 6 amps flow from a 12-volt supply. How many amps will flow through a three-ohm load from a 12-volt supply? (15 amps) (4 amps) (5 amps)

21. Yes. The electrical resistance of a wire, resistor, or other component depends on its physical characteristics. A substance like copper which has many free electrons has little resistance; material like glass has high resistance, and may be considered an insulator. Another factor is the length of the wire or resistor. A given resistive conductor has twice as much resistance, if it is twice as long. Also, a certain material has half as much resistance for a given length

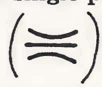
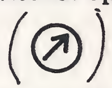
if its cross-sectional area is twice as great.

22. A component or wire's resistance is affected by the material of which it is made, such as copper, aluminum or carbon, and its total length. What else affects electrical resistance? (cross-sectional area) (geometric shape) (geographic orientation)

23. Yes. The resistance, R, of a conductor equals L, the length, over A, the area, times rho, its specific resistance. A 20-ohm resistor could be made of 20 inches of material, one hundredth of a square inch in cross-sectional area, which has a specific resistance of one one-hundredth ohm per inch.

24. This is the symbol for a resistor. It is used in diagrams of electrical circuits, which provide a better picture of the way current flows in the actual circuit than pictures or drawings of the physical layout, which may be overlapping or confusing.

25. Circuit diagrams or plans are also known as schematic diagrams. Most of the symbols are generally standardized and accepted by most users. These symbols are for switches, described as "single-pole-single-throw", "single-pole-double-throw," normally-open and normally-closed plunger switches, and double-pole switches, or two single-pole switches operated together. Which symbol at the bottom stands for a resistor?

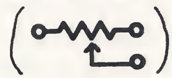




26. Here are two methods of showing if wires shown crossing on diagrams are joined or not joined. Also, sometimes a draftsman will show joining with a bead, from system two, and non-joined wires with a hump, from system one.

27. Here are the symbols for motors, DC generators and alternators, fuses, circuit breakers and lamps. Look them over carefully before you go on.

28. These symbols are for fixed and variable resistors, and resistors used as a so-called rheostat, or as a potentiometer. The potentiometer connects to all three terminals, the rheostat only to one end of the resistor and the moving contact.

29. We will learn about capacitors, ground connections, coils and relays later. Here are their symbols. What is the symbol for a potentiometer?

30. Right. A kilowatt is 1000 watts. Five kilowatts is 5,000 watts. Six kilovolts is 6,000 volts. What is 10 kilo-ohms? (10 ohms) (10,000 ohms) (10,000,000 ohms)

31. Yes. Kilo- means one thousand. Mega- means one million. Their abbreviations are capital K and M. What is 2 megohms? (2,000 ohms) (200,000 ohms) (2,000,000 ohms)

32. Prefixes meaning decimal fractions much less than one are milli-, micro-, nano-, and pico-,

which, respectively, mean one thousandth, a millionth, a thousandth of a millionth and a millionth of a millionth. Notice their abbreviations. What is a milliampere? [.001 amp (a thousandth of an amp)] [.000001 amp (a millionth of an amp)] [.000000001 amp (a billionth of an amp)]

33. The abbreviation for micro is the Greek mu, and the abbreviation for ohm is the Greek omega. The other abbreviations are rather obvious—V, A, and W, for volt, ampere, and watt. In your programs on math for electronics, you learned how to use powers of 10. What is a picofarad? (10^6 farad) (10^{-6} farad) (10^{-12} farad)

34. Right. What is the term meaning rate of work being accomplished by flowing electrons? (amperes) (watts) (power)

35. Right. What is a unit of electrical power? (volt) (watt) (ohm)

36. Yes. What three things are required to complete an electrical circuit? (supply, conductor, load) (voltage, load, watts)

37. Yes. $W = V \times A$. If a 120-volt light bulb pulls 1.25 amps, what power rating should be stamped on the bulb? (150 watts) (60 watts) (100 watts)

38. Yes. 150 watts. How many watts are there in 8 kilowatts? (800) (8,000) (80)

39. Good. What factor limits the flow of current? (voltage) (power) (resistance)

40. Right. What is the name of the unit of resistance? (ampere) (watt) (ohm)

41. Right. You will need to review this material, so be sure you study it carefully before you go on to the next lesson.

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BASIC ELECTRICITY Reference Folder Pe 3

Batteries and Direct Current

1. Most of the things you will learn about electrical and electronic circuits will apply to "direct current" electricity. Direct current is current which flows in one direction only, while "alternating current" changes direction. Many voltage, current and power relationships apply to both DC and AC.

2. Although most electrical power is originally generated as alternating current, most electronics circuits operate on direct current, which is obtained from AC power circuits and transformed to DC. And billions of primary battery cells are used to generate small amounts of portable DC power by chemical transformation.

3. The term "battery" originally meant only a strong assembly of things, as a battery of drums, or guns, or tanks. Sometimes, of course, it means a beating, or hammered pans. For electricity, it means a packaged assembly of two or more single electrochemical generating cells connected in series. Batteries are available in a wide range of sizes. Some small cells and batteries can provide a large amount of power, at least for a short while, and others can provide small amounts of power continuously for a year or more. What kind of current do batteries provide? (AC) (BC) (DC)

4. Right. How does a battery provide electrical energy? (by transforming chemical energy) (by an electrostatic magnet)

5. Of course. A simple cell, originally called the galvanic or voltaic cells after Italian physicists, Luigi Galvani and Alessandro Volta, contains two electrodes, each connected to a terminal, immersed in an electrolyte. The two electrodes are made of different chemical elements, such as carbon and zinc, and the electrolyte is an active chemical, such as sulfuric acid.

6. The electrodes act in two ways. They act as the conductors to the output terminals of the cell, and they supply two of the three chemicals needed to generate electrical power.

7. The third chemical, the electrolyte, may be a complex mixture or solution, and in two or more parts, and either a liquid, gas, or semi-solid paste. The electrolyte reacts chemically with the two electrodes, which make up the three chemical components of a cell. There may be a separate container which has conducting or insulating properties. How would you define a battery? (monolithic conductor) (malleable system) (series assembly of electrochemical cells)

8. Right. There are two general types of cells, the usually expendable primary cell and the secondary or rechargeable cell. The typical primary cell is a carbon-zinc-electrode flashlight cell with a paste electrolyte. The typical secondary cell is in an automobile battery, which uses lead and lead electrodes, and sulfuric acid electrolyte.

9. In the primary cell, the chemical action eats away one of the electrodes, and partly neutralizes the electrolyte. The process cannot be conveniently reversed. In wet galvanic cells, however, the zinc electrode and electrolyte can be replaced and the cell can be used again, while dry cells are just discarded and replaced. Why do we call a flashlight cell a "dry cell"? (It has a semi-solid paste electrode.) (It gets very dry when it discharges.)

10. Yes. A secondary cell has two electrodes and an electrolyte, all three of which are chemically changed as the cell discharges. This change is essentially reversed when a reverse electric current is forced back through it in the recharging cycle. What is a good example of a secondary cell battery? (a double cell flashlight battery) (an automobile lead-acid battery)

11. Right. Even a secondary cell, however, has a limit in the number of charge and discharge cycles it can sustain without deterioration of its elements. At the same time, a primary cell can accept a slight amount of energy from so-called "chargers." However, don't let the slight similarities between primary and secondary cells hide their very real differences.

12. The voltage developed across the electrodes of a single cell is essentially constant for certain combinations of electrode elements and the electrolyte chemical. This is due to the atomic structure of the elements and their electron orbits, which produce ions or deficient atoms. The movement of ions, and the counterflow of electrons, makes up the electric current. The tendency to flow, that is, the concentration or ion "pressure," creates the characteristic voltage of the cell.

13. In a carbon-zinc cell, the zinc is gradually converted into a chemical compound with part of the electrolyte, and in doing so gives up energy in the form of electricity. In the case of a sulfuric acid electrolyte, the zinc is converted into zinc sulfate. Hydrogen is released in the process, which must be absorbed or vented, and water is formed which dilutes and weakens the electrolyte.

14. One type of rechargeable battery cell, the nickel-cadmium cell, is somewhat more costly to produce, but is relatively light, rugged, and powerful. It can be recharged through a large number of cycles. It has a potassium hydroxide electrolyte. What sort of battery is made of nickel-cadmium cells? (primary) (secondary)

15. Some battery cells are intended for voltage reference only and are used in instruments for standards. They cannot provide any material amount of current without damage, so they are often referred to as "open current" reference cells or batteries.

16. After heavy use, hydrogen bubbles may surround an electrode and reduce cell capacity. The cell is said to be temporarily "polarized," and chemicals can be used which are designed to reduce this. A battery has little or no capacity for supplying electrical energy after the electrolyte has been weakened, or one of the electrodes has been eaten away or entirely converted to another compound. How would you describe such a battery? (fresh) (lively) (dead)

17. A cell with electrodes of carbon and zinc in a dilute sulfuric acid electrolyte will generate 1½ volts. An automobile lead-acid cell will provide 2.1 volts. A carbon-zinc "dry cell" with a paste of ammonium chloride, often called "sal ammoniac," zinc chloride, graphite and manganese dioxide will also give 1.5 volts. How many cells are there in most auto batteries? (6) (9) (12)

18. What is the nominal no-load voltage of a five-cell flashlight? (5 V) (7½ V) (10 V)

19. Yes, five 1½ volt dry cells in series would be 7½ volts, and six 2-volt lead cells give 12 volts. A series connection is one which connects the negative terminal of the first battery to the positive terminal of the second one, and so on. The positive electrode of the first cell and the negative electrode of the last cell then provide the power terminals of the whole series. In a flashlight which connects 3 dry cells in series, what is the nominal voltage? (1½ V) (3 V) (4½ V)

20. Yes. The nominal voltage is the approximate no-load voltage. In the case of dry cells used in emergency portable devices, such as flashlights, the usual current loads are quite heavy for the light-duty cells, and their internal resistance causes the effective voltage to be reduced, often to as low as 1¼ volts or less per cell.

21. The dry cell's voltage rises again, however, after the heavy current has been switched off. Since dry cells are designed for intermittent, low-duty cycle use, the paste electrolyte normally stabilizes, and excess hydrogen on the carbon electrode is removed by the manganese dioxide.

22. In this way, good quality, light weight carbon-zinc dry cells can be used for many short periods and a reasonable life. Other primary dry cells use an alkaline electrolyte for longer life at high currents, and cells which contain mercury for lower internal resistance. Can primary cells be recharged? (certainly, many times) (not really very well)

23. Right. What is the nominal no-load voltage of this arrangement of flashlight cells? (4 V) (6 V) (8 V)

24. Yes. What is the voltage of this arrangement of #6 carbon-zinc dry cells? (1½ volts) (6 volts) (8 volts)

25. Yes. They were in series. When cells or batteries are connected in series, their voltages are added, but their current-supplying capacity or rating is not changed. If you have an electric device, such as a motor or lamp, which requires a higher voltage than one battery provides, additional batteries may be connected in series. But if it requires more current than a battery can effectively supply, additional batteries must be connected in parallel, or even in series-parallel.

26. Batteries connected in parallel, with positive electrodes connected together and their negative electrodes connected together, can provide as many times more current as there are parallel batteries or cells. The voltage provided, however, is exactly the same as one battery. If you had six lead acid cells connected in parallel, what voltage would be available? (2.1 volts) (6.3 volts) (12.6 volts)

27. Yes. If you decided that a number 6 dry cell at 1½ volts was capable of supplying one ampere for your device at its expected intermittent use, but you needed 3 volts at 2 amperes, you would connect two cells in series, in parallel with two more cells in series. In this way you would have the voltage force, or pressure, of two cells, and the extra current capacity of an additional pair in series with each other, and in parallel with the first pair.

28. If you decided that you needed 12 volts for your travel trailer lighting system, but one 12-volt auto battery wasn't quite enough current capacity, how would you connect another 12-volt battery? (in series) (in parallel)

29. Right. To some extent, of course, an additional battery in parallel may provide slightly more voltage to a heavy load, since its internal resistance is then in parallel with the first battery, and the internal voltage drop which would occur in one battery will be less, since only half as much current is flowing from each battery.

30. In some respects, the commonly-used rating of "ampere hours" is somewhat misleading, since this is not a measure of actual electrical energy capacity of a battery, unless the voltage is specified. In most cases, it is assumed, or separately indicated, as in automobile batteries. The standard unit of electrical energy is the joule, which equals a watt-second, a watt of power flowing for one second.

31. There are 3600 seconds in an hour. How many joules are available from a 10-volt, 10 ampere-hour battery? (3600 joules) (36,000 joules) (360,000 joules)

32. Right, 360,000 joules, or 360 kilojoules, or 100 watt-hours. This would light a 10-watt bulb for 10 hours or a 100-watt bulb for one hour, assuming the bulbs were designed for the voltage available. Since the voltage is often ignored or assumed, often the current only is mentioned. If a battery is rated at 30 ampere-hours, it could supply, for example, 3 amperes for 10 hours.

33. If a storage battery has been discharged at a rate of one ampere for 5 hours, it would require later recharging at the rate of one ampere for 5 hours, or perhaps 5 amperes for one hour, in order to make up for the energy supplied from the battery. In fact, slightly more current and time may be required to put the energy back into chemical form. And materially more voltage, perhaps 10 or 20% more, will be required to overcome the internal resistance again, this time in reverse.

34. If you have a 12-volt system on your boat, and a 20 ampere-hour battery, how long could you light your 100-watt distress lamp, out on the lake at night after your engine conked out? (1.2 hours) (2.4 hours) (12 hours)

35. Correct. Maybe you should have a smaller lamp or a bigger battery. In many commercial and industrial applications, batteries are intended for intermittent, emergency or standby applications. In some applications, they provide a way of storing energy from intermittent supplies like wind-chargers or gasoline generators. In automobiles, of course, they provide a source of starting energy and a reservoir of energy for other occasional heavy loads, or the simultaneous use of several devices.

36. Unfortunately, storage or secondary batteries at present are either not very small or light, or are rather expensive for a substantial energy storage capacity, so they are only marginally suitable for primary vehicle power, or for main fixed utility power. They are particulary useful, however, for fixed standby or reference energy storage in remote applications, or where it is critical that no interruptions in service occur, as in hospitals or key industrial systems.

37. Which of these would be the most likely battery applications? (racing auto, rail locomotive, aircraft propulsion) (hearing aid, digital watch, portable transceivers) (electric utility, central heating, refrigeration)

38. The internal resistance of a cell depends upon the size of the electrodes, the distance between them, and the concentration of the electrolyte. The larger and closer the electrodes, and the stronger the electrolyte solution, the lower is the resistance, subject to other general design factors.

39. A lead-acid storage battery is usually designed with each electrode having many large flat surfaces closely spaced from the opposite electrode. What characteristic does this large surface area and close spacing improve? (ruggedness) (high resistance) (low internal resistance)

40. Although virtually all of the power used in electronic circuits comes from electric utility supplies, a tiny but important part is obtained from batteries of one type or another. You should be careful to observe proper battery use procedures to protect equipment and your own safety.

The Color Code of Resistors

1. The simplest and cheapest electronic component is the resistor. Its symbol is a sawtoothed line, and it resists or limits the flow of electrical current. It is often small, of low power rating, and relatively low in cost. Which of these would you guess is the least expensive? (capacitor) (resistor) (transistor)

2. In electronic circuits, resistors are used to limit current in a circuit where reduced current is desired and to reduce the voltages at points where reduced voltage is required. Resistors are also used as a signal "load," or a "dummy load," to establish voltages which can then be amplified, referred to, or even further reduced. Since resistors are relatively small, cheap, simple, and reliable, they are very widely used.

3. Fixed value resistors are usually made of carbon rod, carbon film on a ceramic form, or a metal wire or film. Resistors made of a metal wire, such as manganin and wound on a form are quite stable in resistance, and can carry more current than carbon. Some "fixed" resistors can be "adjusted" by sliding clamps. They are disigned to handle some power.

4. Variable resistors, rheostats, and potentiometers are also made with a carbon or resistor wire and usually have a rotating shaft which moves a slider contact. Most potentiometers are not designed to handle or dissipate much power, so they should be selected to avoid large current loads.

5. Resistors are generally so small and inexpensive that they cannot carry a resistance value or precision rating printed on them. Furthermore, it is desirable to mount them in a circuit without concern about which side or edge is visible, so it is important to mark their values so that they are immediately visible at a glance from any angle. This is done by use of a color code and painted rings on each resistor.

6. The resistance value and the tolerance or precision resistance value rating are indicated by the color-painted rings. The power rating is generally not shown, but it is assumed from the size of the resistor. What could you learn from the color bands of this resistor? (power rating) (tolerance) (resistance and tolerance)

7. Here is a list of the colors used on resistors and the numbers they stand for. Look at them a minute or two and then push the center button when you are ready to go on.

8. Here is a little help, from the ground up, one might say, to help you remember the colors and their numbers. In any case, you should probably repeat this program two or three times to get practice to make sure you learn it. Let's say zero is under the ground. What is its color? (blue) (red) (black)

9. Yes. Right on the ground is one. What is its color? (black) (brown) (red)

10. Right. Another earth or clay color not far from brown is red. What does it represent? (1) (2) (3)

11. Yes, two. A color next to red stands for three. What color is this? (orange) (yellow) (green)

12. Correct, orange. And going one, two, three from brown to red to orange, what do you think should be next to represent four? (yellow) (green) (blue)

13. Yes. Brown, red, orange, and yellow might be thought of as earth or clay colors, but what color is just above the earth? The color of grass or tree leaves (or perhaps the color of money) stands for 5. (green) (blue) (violet)

14. Right, green. Above all the earthbound things, we look at the sky. Its color stands for 6. What color represents 6? (gray) (violet) (blue)

15. Yes, blue. Another color that might be seen in the atmosphere is the color we use for 7. What is it? (violet) (gray) (white)

16. Right, violet. Eight is gray, and nine is just white. Beyond the atmosphere we lose all color. Here is the complete list again; so, take a moment to memorize them before going ahead for some practice. Push the middle button to go on.

17. What color represents 2? (black) (brown) (red)

18. What number does yellow represent? (3) (4) (5)

19. Which of these sets of colors represents 1,2,3,4, and 5? (brown, red, orange, yellow, green) (black, brown, red, orange, yellow)

20. What numbers does this series of blue, violet, gray, and white represent? (1,2,3,4) (3,4,5,6) (6,7,8,9)

21. What does green represent? (4) (6) (5)

22. What number is gray? (7) (8) (9)

23. Here is a resistor whose colors, representing the first two digits of its resistance value, are yellow and violet. What are the first two digits' value? (47 ohms) (52 ohms) (10 ohms)

24. Right. What are the first two digits of this resistor's value? (27 ohms) (47 ohms) (33 ohms)

25. Right. The third band is not used as a significant digit number; it signifies the number of zeroes added to the first two digits. Thus, this resistor is a 47,000-ohm resistor, because of the 4 and 7 represented by yellow and violet, and the 3 zeroes represented by the orange band in the next position. The silver band indicates that the resistor is actually within 10% of the specified value. What is the value and tolerance of the resistor at the bottom? (470 ohms, 10%) (4700 ohms, 10%) (47,000 ohms, 10%)

26. Yes. What's the value of this resistor? (100 ohms) (1,000 ohms) (10,000 ohms)

27. Which of these resistors is a 100,000-ohm resistor? (A) (B) (C)

28. Which color sequence shows a 350-ohm resistor? (orange, green, brown) (blue, brown, yellow) (black, gray, orange)

29. Yes. When there is a gold band, it shows the resistor has a 5% accuracy tolerance. What is the value and tolerance of this resistor? (483 ohms, 5% tolerance) (39,000 ohms, 5% tolerance) (3,300 ohms, 20% tolerance)

30. What is the value of a resistor with a color band sequence of red, gray, red, and silver? (393 ohms, 10% tolerance) (14,000 ohms, 5% tolerance) (2,800 ohms, 10% tolerance)

31. Which color band indicates a 10% tolerance? (silver) (gold) (green)

32. Here are some of the more common resistor values used in electronic circuits. Each is about the same ratio larger than the next lower value. That is, there is about the same % increase in resistance in each succeeding larger value. Also, the values in 2nd, 3rd, and 4th columns are multiples of 10,000, and 1,000 times the number in the 1st column. There are, of course, resistors made at values inbetween these values, but less often.

33. You have learned that the color code of resistors consists of 4 bands. The 1st and 2nd bands give the integer values 0 to 9, and the 3rd band uses these same colors to indicate the decimal multipliers, or the number of zeroes to apply to the 1st 2 integers. The 4th band is silver for 10% tolerance and gold for 5%. If there is no 4th band, the tolerance is 20%.

34. Sometimes there is a fifth band; if it is yellow, it means only one failure per million hours. Such resistors are very rare at present, and only used for special military and space applications.

35. This is a very common resistor. What is the value and tolerance? (2,700 ohms, 10%) (4,700 ohms, 10%) (4,700 ohms, 5%)

36. What is the value and tolerance of this resistor? (4,500 ohms, 10%) (2,500 ohms, 5%) (2,500 ohms, 20%)

37. Sometimes you will see color-coded resistors with values less than 10 ohms. When this occurs, a gold band in the 3rd position will signify a decimal point between the 1st and 2nd digit; for example, a yellow, violet, and gold resistor will mean 4.7 ohms. The 4th band will continue to mean tolerance, as usual. Push the middle button to go on.

38. When the resistor is less than one ohm, a silver band is used in the third place, and it means a decimal point in front of the two digits. A red, violet, and silver resistor is .27 ohm. Push the middle button to go on.

39. What is the value and tolerance of this resistor? (2,300 ohms, 20% tolerance) (.10 ohm, 5% tolerance) (1.8 ohms, 10% tolerance)

40. What is the value and tolerance of this resistor? (820 ohms, 10%) (2,8 ohms, 5%) (280,0υ0 ohms, 20%)

41. This is the end of your lesson on the Color Code of Resistors. Be sure to repeat this lesson as much as you need to help you remember what you have learned.

BASIC ELECTRICITY Reference Folder Pe 5

Ohm's Law—How to Use It

1. A complete electrical circuit must have a voltage source, conductors to carry the current, and a load to use the energy. If these three things are present in a circuit, what three kinds of electrical quantities could you measure? (voltage, resistance, current) (load, weight, movement) (length, width, height)

2. Yes, voltage, resistance, and current. In any complete electrical circuit, voltage or electric pressure forces the current, or flow of electrons, to move and to provide power for a load. Every electrical circuit, regardless of its complexity, works in this manner. How would you describe voltage? (flow of electrons) (unit of power) (electrical pressure)

3. Yes. This schematic shows a circuit made up of a 6-volt battery, a 6-ohm resistance, and a switch to enable us to start and stop current flow. How much current do you think will flow when the switch is closed? (1 amp) (2 amps) (3 amps)

4. Yes, one amp of current will flow. This is from the basic understanding of Ohm's Law, that a 1-volt source will cause 1 amp of current to flow through a 1-ohm load. What do you think would happen to the current flow if the battery is increased to 12 volts, and the load resistance remained 6 ohms? (increase) (decrease) (no change)

5. Yes, current would increase proportionately, to 2 amps. To increase proportionately means that if the voltage is doubled and the load resistance stays the same, the current flow will double, and if voltage is tripled, current will triple. What do you think would happen to current flow if we kept the original 6-volt battery, but decreased the load resistance to 3 ohms? (decrease, ½ amp) (increase, 2 amps) (remain, 1 amp)

6. Good. Current flow also changes with a change in resistance. But note the difference. Current increased when voltage increased and also increased when resistance was decreased. We can say that current changes directly to a change in voltage, but inversely to a change in resistance. What would happen to current if resistance was decreased to a third of its original value? (decreases 3 times) (increases 3 times) (increases 6 times)

7. That's correct. Decreasing resistance to one-third causes current to increase by three times, an inversely proportionate change. In a circuit, voltage, current, and resistance are related to each other. This relationship is known as Ohm's Law. According to Ohm's Law, what does current do when voltage is decreased? (stays constant) (increases) (decreases)

8. Right, there is a proportionate decrease in current. Now we are ready to express Ohm's Law as a formula. Current, in amps, is equal to voltage divided by resistance in ohms. Or shortened, A equals V over O. Study this formula carefully, then push the center button.

9. Traditionally, Ohm's Law has been written E = IR, or $I = \frac{E}{R}$, with E representing voltage, or electromotive force, and I, current in amperes. Think of electric force, E, equaling intensity of current in amps times resistance in ohms.

10. Here is another electrical circuit having a 20-volt supply and 4 ohms resistance. Use Ohm's Law to calculate the amount of current flowing. (80 amps) (5 amps) (24 amps)

11. Right. We can use Ohm's Law to calculate voltage if we know how much resistance there is in the load and how much current is flowing in the circuit. Voltage = amps × ohms. What voltage is being supplied to this circuit? (48 volts) (19 volts) (42 volts)

12. If the current is 1.5 amps and the resistance is 4 ohms, what is the voltage? (5.5 volts) (12 volts) (6 volts)

13. Right. If we keep the resistance at 4 ohms, but need to increase the current to 15 amps, how would we have to change the voltage supply? (decrease, 9 volts) (increase, 60 volts) (increase, 19 volts)

14. Good. We may also convert the basic Ohm's Law formula to allow us to calculate resistance if we know the amounts of voltage and current. Resistance, in ohms, equals voltage divided by current, in amps—$R = \frac{E}{I}$. What is the resistance in this circuit? (.001 ohm) (400 ohms) (100 ohms)

15. Right, 100 ohms. Here is another circuit with 4 amps connected across 180 volts. How much resistance is needed? (184 ohms) (720 ohms) (45 ohms)

16. Calculate the voltage needed for this circuit having 10 ohms and 1.5 amps. (12 volts) (6 volts) (9 volts)

17. Yes. Study this circuit with a 12-volt supply and 24 ohms of resistance. How much current is flowing? (½ amp) (2 amps) (0 amps)

18. That's right. Here are the three forms of Ohm's Law. Current can be found by dividing voltage by resistance, or $I = \frac{E}{R}$. You've already seen that E = IR. Resistance is calculated by dividing voltage by current, or $R = \frac{E}{I}$. Study them, then push the center button.

19. Here is a memory aid that will help you remember Ohm's Law formulas. The filled-in illustration has letter symbols for voltage, amps,and ohms. This memory aid is used by covering up the unit being calculated and leaving the rest of the formula showing. To calculate amps of current, cover the A with a finger and read the formula as V over O. How many amps flow in a circuit with a 15-ohm resistance and a 1.5-volt battery source? (100 amps) (1 amp) (.1 amp)

20. Right, one-tenth of an amp, or 100 milliamps. The prefix "milli" means "thousandths of." We often use milliamps to describe currents of less than one amp. To find the number of milli-

amps, move the decimal point three places to the right because there are 1,000 milliamps in one amp. How many milliamps are there in ¼, or .250 amps? (250) (2,500) (25)

21. Yes, 250 milliamps. On your formula memory aid, what letter do you cover if you want to know the formula for finding resistance? (volts) (amps) (ohms)

22. Right, cover the O to find ohms. How much resistance should you connect to a 24-volt supply if you want it to draw 750 milliamps of current? Here is a hint. Always convert the problem to basic units of volts, amperes, or ohms, when working the Ohm's Law formulas. Then we should write 750 milliamps as .75 amps. Now calculate your answer. (32) (18) (24)

23. Yes. You need a 32-ohm resistor to limit the current flow to 750 milliamps. A resistor is an electrical component made of materials that limit or resist current flow. How much current will flow from a 12-volt source through a 1200-ohm resistor? (24 amps) (100 amps) (.01 amp)

24. That's right, only .01 amps or 10 milliamps. Use your memory aid again to find the formula for voltage. Cover the word voltage. How do you read the formula? (volts = amps × ohms) (volts = $\frac{\text{ohms}}{\text{amps}}$)

25. Right, V = amps × ohms, or I × R. If the circuit could be damaged if more than 500 milliamps of current flowed through it, and you have a 100-ohm resistor to limit the current flow, how many volts may you apply? (12) (50) (5)

26. You have learned that the electric power used in a resistor equals the product of the voltage across it and the current through it. P, in watts, equals E, in volts, times I, in amps.

27. And you have also learned from Ohm's Law that the values of current, in amps, and voltage are affected by the resistance, in ohms. We can combine the electric power formula, P = IE, with Ohm's Law, E = IR, to get P = I × IR. or $P = I^2R$. Check this carefully before you go ahead.

28. How much power is used in a 3-ohm resistor carrying 2 amps of current? Use $P = I^2R$. [(2^2) (3); (4) (3); 12 w.] [(2) (3); 6 w.]

29. Yes. In this complex electronic circuit, we measure 15 milliamperes flowing through the 10-K resistor. What's the voltage across it? [E = IR; volts = (.015 amp) (10,000 ohms); volts = 150 volts] [E = IR; volts = (.15 amp) (10,000 Ω); volts = 15 volts]

30. Yes. What was the power being dissipated in the resistor? [watts = I^2R; W = $(.15)^2$ (10,000); W = 15 watts] [W = EI; W = (150) (.015); W = 2.25 watts]

31. Right. What is the maximum current for which a 1-watt, 1 K-ohm resistor is rated? ($P_{watts} = I^2R$; $I^2 = \frac{P_w}{R}$; $I = \sqrt{\frac{P}{R}} = \sqrt{\frac{1}{1000}} = .0316$ A.) ($P = I^2R$; $I^2 = \frac{P}{R}$; $I = \frac{\sqrt{P}}{R} = \frac{\sqrt{1}}{1000} = 100$ ma)

32. Yes. How many milliamps are there in .0316 amps? (31.6 ma) (316 ma) (3160 ma)

33. When a resistor is wired into an electronic circuit, it is usually much easier to measure the voltage across it, and to read the value of its rated resistance from the color bands, than to measure the current through it or to find the power it is using. This is because a high-resistance voltmeter can be easily connected across it without disturbing the circuit or disconnecting leads.

34. This 2.7 K resistor is the collector load resistance of an amplifier transistor, and the voltage across it is 5.4 volts. What is the current through it? (2 mils) (5 mils) (20 mils)

35. A milliwatt, you remember, is a thousandth of a watt. How many milliwatts are being dissipated in the 2.7 K resistor, carrying 2 mils of current? (1.08 milliwatts) (10.8 milliwatts) (108 milliwatts)

36. How many kilowatts are there in 1320 watts? (1.32 kw) (13.20 kw) (132 kw)

37. An electric heater draws 12 amperes from a 120-volt supply. What is its hot resistance, and power rating? (10 ohms, 1440 kw) (10 ohms, 1440 watts) (100 ohms, 1440 watts)

38. How many milliamps are there in .65 amps? (.65) (65) (650)

39. Right. What is another name for the diagram of an electric current? (circumference) (schematic) (dialog)

40. Yes. You will need to practice a lot on the use of Ohm's Law, so it will be easy for you to apply in any circuit. In the next program, you will learn about series and parallel resistors.

BASIC ELECTRICITY Reference Folder Pe 6

Series and Parallel Circuits; Kirchhoff's Laws

1. You have learned about the current and voltage relationships in individual resistors, and in simple series and parallel combinations of them. But when they are in use, resistors, electric power sources, such as batteries, and other electrical components are always parts of complete circuits. Some of these electrical circuits are quite complex, and an analytical process is necessary to understand them.

2. One law which is necessary, and which you will learn to use easily, is Kirchhoff's Voltage Law. It states, quite obviously, that as you go around a circuit, the amount of voltage rise in the circuit must equal the total voltage drop experienced in the same circuit.

3. If you sailed your boat from the dock, wouldn't the distance travelled north equal the distance travelled south, when you returned to the dock? (yes) (no)

4. Yes, and if you started out at sea level and took a trip to the mountains, the sum of the rises in elevation would equal the sum of the drops. This would also be true if you started from a point part-way up, and returned to that point. Kirchhoff said "the algebraic sum of the voltage differences in any closed electrical path in a circuit is zero."

5. In this simple circuit, two resistors are connected in series across a 12-volt battery. The 4-ohm resistance and the 2-ohm resistance provide a total resistance of 6 ohms to the 12 volts, so that from Ohm's Law, we know that 2 amps will flow. If you connected a voltmeter across the battery, you would find an increase in positive voltage potential on the positive terminal, as compared to the negative terminal. As we proceed in a clockwise direction down through the upper resistor, what do we find? (no change) (a drop in positive voltage) (an increase in voltage)

6. Yes. We'll refer to this IR (resistance-current) voltage as a voltage "drop," and the voltage "drops" again as we proceed clockwise around the circuit through the lower resistor, until we arrive at the point where we began. The sum of the voltage rises and drops are zero.

7. The voltage rise across the battery is 12 volts. What are the voltage drops across the resistors? (4 V + 8 V = 12 V) (6 V + 12 V = 18 V)

8. You know that the algebraic sum of values means that their positive and negative signs must be considered when adding. This also means that we must consider the polarity of the voltage in summing. If we start from the lower or negative terminal of the battery in this circuit, for example, we will raise the voltage 100 volts positive as we go through the battery. Then, as we go from that point through the resistors, we will go from positive to negative or less positive junctions, resulting from the IR, or current-resistance, voltage drops.

9. The battery raises the voltage 100 volts when referred to its negative terminal. The upper resistor is found to generate a 25-volt "voltage drop." The lower resistor generates a 50-volt drop. What is the voltage that could be measured directly across the center resistor? (25 V)(50 V) (75 V)

10. Yes. If the voltage were measured across both of the lower resistors, it would be 75 volts, and across all the resistors, it would, of course, be 100 volts, the same as the battery.

11. In direct current circuits, it is important that the polarity of the circuit points at each end of resistors or other elements be identified at least by implication. The polarity of batteries and other power sources is always specified, but the polarity of voltages across resistors depends upon the direction of current flow. The voltage, or potential at the point just below the upper resistor is negative with respect to the top of the resistor, but it is positive with respect to the point below the lower resistor.

12. In practice, you may apply Kirchhoff's Voltage Law by beginning at some relatively common point, such as ground or the most negative terminal of the power source. Then proceed along a selected path, and assign relative polarity markings across the circuit elements. In many cases, you will start at the negative terminal of the power source, go first to its positive terminal, then return to the negative terminal by a selected resistive or load path. What is the algebraic sum of the voltages in any completed path through a circuit? (zero) (12 volts) (–12 volts)

13. In this circuit, the algebraic sum of the 24-volt rise in the battery and the three resistor drops is, of course, zero. In any single-path series circuit, there is only one current. Could we say then that the algebraic sum of positive 24 volts, plus the negative voltages generated by 3 ohms times the current, 4 ohms times the current, and 5 ohms times the current equals zero? (yes) (no)

14. Yes. Since we completed an entirely closed path through the circuit, the algebraic sum of the voltage changes must be zero as you return to the starting point. Since 24 – 3(I) – 4(I) – 5(I) = 0 and 24 – 12(I) = 0, what is the current in this circuit? (2 amps) (3 amps) (4 amps)

15. Yes, and the voltage drops across the 3-ohm, 4-ohm, and 5-ohm resistors are, respectively, 6 volts, 8 volts, and 10 volts. Measured from the negative battery terminal, what would be the voltage potentials at the top of each resistor? (24 V, 12 V, 6 V) (20 V, 12 V, 6 V) (24 V, 18 V, 10 V)

16. Right. In this circuit, there's a 4-volt battery on the right which "bucks" or opposes the larger 12-volt battery on the left, as you can see by tracing around the complete circuit. The total positive voltage rise when going clockwise is only 12 volts, and the voltage drops include a 4-volt drop in the smaller battery which doesn't depend on the current flow. What is the voltage equation for this circuit? [12 – 3(I) – 4 – 5(I) = 0] [12(I) – 3(I) + 4 + 5(I) = 0]

17. Yes. What is the current in this circuit? (1 amp) (2 amps) (3 amps)

18. Correct. What are the respective potentials at the tops of the upper resistor, the 4-volt battery

and the lower resistor, referred to the grounded 12-volt battery negative terminal? (12 volts, 6 volts, 4 volts) (12 volts, 9 volts, 5 volts)

19. Right. Here is almost the same circuit, but it has the 4-volt battery connected so that it assists the current flow through the circuit which is mostly due to the 12-volt battery. What is the equation of this circuit? [$12 - 3(I) - 4 - 5(I) = 0$] [$12 - 3(I) + 4 - 5(I) = 0$]

20. Right. Collecting terms, we get $16 = 8(I)$, so the current is 2 amps. Now, what are the respective voltages at the tops of the upper resistor, the 4-volt battery and the lower resistor, referred to the grounded 12-volt battery negative terminal? (12 volts, 6 volts, 10 volts) (12 volts, 10 volts, 6 volts)

21. There is another Kirchhoff's Law. This is Kirchhoff's Current Law, and it is used when there is more than one path for the circulating current. In what kind of a circuit do you think this would occur? (single series circuit) (parallel circuit)

22. Right. In this parallel circuit the current supplied by the battery divides into two paths, part of it becoming I_1 and going through R_1, and I_2 flowing through R_2. If there were a 12-volt battery, and two parallel 6-ohm resistors, 2 amperes would flow through each resistor, and the total of 4 amps would flow through the battery.

23. Kirchhoff's Current Law states that the total current in a line equals the sum of the currents in the branches. Or you may say that the sum of the currents entering a junction point, or "node" equals the sum of the currents leaving it. This sounds obvious, since the electrons must have someplace to go.

24. Another way of saying Kirchhoff's Current Law is "the algebraic sum of the currents to any point is zero."

25. Let's consider this circuit. The 8-ohm and the 6-ohm resistors are connected in parallel across the 24-volt battery. The current from the battery is the current to the junction N. The current from the junction is the total of I_1 and I_2 through resistors R_1 and R_2 of 8 and 6 ohms. What is the equation for the current to junction N? [$I_{total} - I_1 - I_2 = 0; I_{total} - \frac{24}{R_1} - \frac{24}{R_2} = 0$] [$I_{total} + I_1 + I_2 = 0; I_{total} + 24R_1 + 24R_2 = 0$]

26. Yes. We can transpose the equation, and say that the total battery current equals $\frac{E_1}{R_1} + \frac{E_2}{R_2}$, which is $\frac{24}{8} + \frac{24}{6}$. What is this? (6 amps) (7 amps) (8 amps)

27. Look at this circuit. It looks more complex. You should notice that current flow in the circuit is reversed here. In electronics circuits, current can be shown flowing from a high concentration of electrons to a lower or more positive point. This is called "actual" current flow and has been used in previous frames. The way shown here illustrates "nominal" current flow which shows current flowing from a high or positive potential to a lower potential. Both methods are used

frequently, so be sure you understand them. How many current loops or branches are there? (2) (3) (4)

28. Yes. Let's look at the same circuit, drawn a little differently. It looks simple this way, but you can't rely on most circuit draftsmen to draw them so they are easy to follow, so you may have to remember where each conductor goes. There is no reason why you should be unnecessarily confused, so in these programs the resistors and other elements which primarily generate voltage drop will be drawn vertically, and only components which have primarily coupling functions will be drawn horizontally. But you should be careful about other circuits you see.

29. First, let's find the first branch current I_1, the current through the 10-ohm resistor. We can do this by using Kirchhoff's Voltage Law around the branch loop, including it and the battery. Starting at the battery's negative terminal, we get +20 for the battery, $-R_1 I_1$ which is $-10(I)_1$ for the IR drop, equals zero. What's the solution of this equation? [$20 = 10(I)_1 ; I_1 = 2$ amps] [$20 = 10(I)_1 ; I_1 = 10$ amps]

30. Yes. Now for the branch loop through the battery and the three resistors. What's the equation here? [$20 - 3(I)_2 + 5(I)_1 - 2(I)_2 = 0$] [$20 - 2(I)_2 - 3(I)_2 - 5(I)_2 = 0$]

31. Right. Combining terms and transposing, we get $10(I)_2 = 20$, and I_2 is 2 amps. Now if I_1 is 2 amperes and I_2 is 2 more amps, what is I_t, the total current through the battery, as given by Kirchhoff's Current Law? (0 amps) (2 amps) (4 amps)

32. Right. You should also notice that there is another closed path or loop in this circuit, around which you could apply Kirchhoff's Voltage Law. This is the loop through the resistors only. Starting at the lower junction, for example, you would find that the total voltage rises would equal the total voltage drops as you returned to the starting point. When the circuit is drawn in this way, it may be easier to see than if the resistors were drawn horizontally, or voltage rises were occasionally reversed in direction.

33. Here's a parallel circuit. The voltage equation for the clockwise loop through the battery and the 6-ohm resistor is $12 - 6(I)_1 = 0$, so I_1 is 2 amps. What's the voltage equation for the loop clockwise through the three resistors? [$(+6\Omega)(2\text{ amp}) - (8\Omega)(I_2) - (4\Omega)(I_2) = 0$] [$6 - 8 - 4 = 0$]

34. Yes, collecting terms and transposing, we have $12(I)_2 = 12$. What is I_2? (1 amp) (12 amps) (144 amps)

35. Yes. Was the current the same all the way around the resistor-only loop? (yes) (no)

36. No, the 6-ohm resistor had a current of 2 amps, while the other resistors had only 1 amp. But the equation was a voltage equation, with total voltage rises and drops equal. The higher total resistance of the 4- and 8-ohm resistors in series generated the same voltage drop that appeared in the 6-ohm resistor carrying a higher current.

BASIC ELECTRICITY Reference Folder Pe 7

Analysis of Series-Parallel Circuits

1. In the previous lesson you learned that Kirchhoff's Voltage Law states that in a single closed circuit loop, or current path, the voltage rises and drops algebraically add up to zero. And you learned that Kirchhoff's Current Law states that the algebraic sum of currents entering and leaving a junction point is zero.

2. You learned that the voltage law is true, even for circuit loops, part of which carry currents different from other parts of the circuit. Is this true for loop "R"? (yes) (no)

3. Yes. The effective resistance of two parallel resistors equals the product of their resistance values over their sum. What is the effective resistance of 3 ohms and 6 ohms in parallel? (2 ohms) (4 ohms) (9 ohms)

4. Yes. Let's see what the effective resistance of 3 ohms, 6 ohms, and 2 ohms would equal. First, for purposes of total load or the power supply, the 3-ohm and 6-ohm resistors combined could be replaced, we found, by a 2-ohm resistor. Then what would be the effective resistance of two 2-ohm resistors combined in parallel? (1 ohm) (2 ohms) (4 ohms)

5. Yes. And if there were another parallel resistor, we could combine it by another similar step. For practice, let's find the equivalent resistance of these four resistors in parallel; an 8-ohm, another 8-ohm, a 12-ohm, and a 6-ohm resistor. Starting at the left, we know, of course, that the two 8-ohm resistors are equivalent to one resistor of half their value, or 4 ohms. This also results from the product-over-the-sum step. Which is correct? [$\frac{(8)\cdot(8)}{88} = 4\,\Omega$] [$\frac{8+8}{64}$ = 4 ohms] [$\frac{(8)(8)}{8+8} = \frac{64}{16}$ = 4 ohms]

6. Right. Now when we combine the resulting 4 ohms, representing the effect of the first two 8-ohm resistors, with 12 ohms, what do we get? [$\frac{(4)(12)}{4+12} = \frac{48}{12} = 3\Omega$] [$\frac{(4)(12)}{4+12} = \frac{42}{14} = 3.5\,\Omega$]

7. Yes. Now combine the 3 ohms equivalent to the first 3 resistors with the 6-ohm resistor. What do we get? [$\frac{(3)(6)}{3+6} = \frac{18}{9} =$ 2 ohms] [$\frac{(3)(6)}{(3+6)} = \frac{36}{6} =$ 6 ohms]

8. Yes. Since the effective resistance of resistors in parallel can also be expressed as the inverse of the sum of the inverses of the various resistors, we could also say that the effect of the resistors in the previous example can be obtained by taking the inverse of the sum of $\frac{1}{8}, \frac{1}{8}, \frac{1}{12}$, and $\frac{1}{6}$. This is simple to do with a calculator using decimal conversions, and by adding .125 to .125 to .083 to .167. This gives 500 thousands, or ½ which, inverted, is 2 ohms. Check these figures, then go ahead.

9. You have learned about simple series circuits, and about parallel circuits. In one case you have studied a parallel circuit of which one branch had series resistors.

10. This is a series parallel circuit, quite typical of electrical and electronics systems. So that we can think of it more easily, let's redraw it this way.

11. Immediately we can see that one way to find the circuit voltages and currents is to combine the parallel resistances to their equivalent. What is it? [24K + 8K = 32K] [$\frac{(24K)(8K)}{(24K+8K)} = \frac{192}{32} = 6K$] [$\frac{24K+8K}{(24K)(8K)} = 12K$]

12. Yes. Now we have 9K and 6K in series, across 60 volts. What's the current? (4 ma) (5.5 ma) (6.67 ma)

13. As 4 mils are flowing in the equivalent series circuit, we can find the voltage potential at the junction between resistors. It is zero at ground, plus the current, 4 mils times the equivalent 6K resistance of the two parallel resistors. What's that? (+24 volts) (+46 volts) (–24 volts)

14. Yes. We can also multiply the 4 mils current times the 9K upper resistor, and get 36, which we subtract from the 60-volt supply and also obtain 24 volts at the junction.

15. There are actually three different currents in this series-parallel circuit. One is the 4-mil series current, and the others are the currents in the two parallel resistors. What does Kirchhoff's Current Law tell us? (Current and voltage are equivalent.) (Since 4 ma enters junction, parallel currents leaving it total 4 ma.)

16. Right. We can simply use Ohm's Law, and since current is voltage over resistance, we divide 24 volts first by 8K, and then 24K, to obtain the currents in the two legs. What are they? (3 ma, 1 ma) (2 ma, 2 ma) (4 ma, 2 ma)

17. Yes. At this point, you may need to check the power used in the resistances. We have shifted from ohms and amps to K-ohms and milliamps without comment. Since they bear a ratio relationship, you must be careful in computing power to use volts and amps to get watts. If you multiply volts times milliamps, you will get milliwatts, so be careful.

18. How much power is used in the 9K resistor? [24V × 4 ma = 96 MW] [36V × 4 ma = 144 MW (.144 watt)] [36V × 4 ma = 1.364 MW (1.364 W)]

19. Yes, about $\frac{1}{7}$ of a watt. We would use a quarter-watt or half-watt rated resistor. The parallel resistors would use even less energy. The series-parallel circuit could have been rearranged like the circuit at left, or its equivalent on the right. Currents, power, and voltage drops would have been the same, but the junction potential between resistors, when referred to ground, would have been changed.

20. Here's a sort of series-parallel-series circuit. Across a 50-volt battery is connected a resistor, in series with a parallel circuit with one resistor in one leg and two series in the other leg. Let's redraw it.

21. This drawing is somewhat easier to understand. What would you do first? (Add all resistances together.) (Add 2K and 6K series resistances; equivalent to 8K) (Add the inverse of 3K and 16K.)

22. Yes. After the series resistors in the parallel branch are added, we can consider the circuit as simply a series-parallel circuit, instead of series-parallel-series. What would be a useful next step? (Find the equivalent of the parallel resistors.) (Add all the resistor values and divide by 4.)

23. Yes. After we find the single-resistor equivalent of the parallel circuit, we have a simple series circuit with resistances which can be combined by addition to obtain the total circulating current, and the principal junction voltages. How do we find the single-resistor equivalent of the parallel circuit? (sum of all resistances) (product divided by the sum)

24. Right. Eight times 16 over 8 plus 16 is 5.33 K-ohms. Add this to 3 K-ohms and we get 8.33K. How do we get the current? (Ohm's Law—$\frac{50V}{8.33K\ \Omega}$ = 6 ma) (Kirchhoff's Law—$\frac{P}{Q}$ = R)

25. Yes. Now to check with Kirchhoff's Voltage Law: Clockwise from the negative battery terminal we get +50 - (6)(3) - (6)5.33 = 0 or 50 - 18 - 32 = 0, which checks out. Note that there are 32 volts across the parallel section. What current do we get through the 16K resistor leg? (2 ma) (3.2 ma) (4.8 ma)

26. Yes. And what law tells us that with 6 milliamps coming to the bottom junction of the parallel section, and 2 mils through the 16K resistor, there will be 4 mils going through the other two resistors at the right? (Kirchhoff's Current Law) (Ohm's Law) (Kirchhoff's Voltage Law)

27. Yes. And knowing that 4 mils is flowing through the two resistors on the right parallel leg, we can find the two voltage drops, across the 2K and the 6K resistors. What are they? (4 × 2 = 6V; 4 × 6 = 10V) (4 × 2 = 8V; 4 × 6 = 24V)

28. Right. The two voltages, of course, add up to the 32-volt/total across the parallel section. We could, at this point, go back and calculate all of the voltages, potential references, and power dissipation in each resistor. You may do this, if you wish, as an extra exercise.

29. If you wish to proceed through the preceding circuit with more mathematical rigor and less intuition, which can't always be applied to complex circuits anyway, you could set up a series of algebraic equations based on Kirchhoff's laws. You could write three voltage loop equations and two current junction equations, but one of the loop and one of the junction equations would be somewhat redundant and unnecessary. What information are we seeking first? (I_t, I_1, I_2, E_1, E_2, E_3) (power losses in all loops)

30. For example, if you were programing a computer to analyze the circuit, you would enter the voltage equations $50 - 3(I)_t - 16(I)_1 = 0$ for the left loop, including the battery, and $16(I) - 6(I)_2 - 2(I)_2 = 0$ for the short loop around the parallel section only. The current equation is $I_t - I_1 - I_2 = 0$.

31. In addition, you could enter in your computer, equations that find the voltages across the four resistors as $3(I)_t$, $16(I)_1$, $6(I)_2$, and $2(I)_2$, and the power dissipation as these respective voltages times their respective currents. What equations could we write for power? [$4(E^2)_1 (R_3)$ = watts] [$(3I_t)(I_t)$ MW in 3K; $(16I_1)(I_1)$ = MW in 16K; $(6I_2)(I_2)$ = MW in 6K; $(2I_2)(I_2)$ = MW in 2K]

32. You will recall from algebra that for three equations and three unknowns, we could take the equations in pairs, multiply both sides of one of them suitably, and subtract or add them to eliminate one variable. Or we can solve one equation for one variable, and substitute its value in the other two equations, then solve these last two by subtraction to eliminate another variable. After finding the value of the remaining variable, we substitute it back into the previous equations. Let's try this latter method.

33. Solve $I_1 + I_2 = I_t$ for I_2, and we get $I_t - I_1$. Substitute $I_t - I_1$ for I_2 in the second voltage equation and we have $16I_1 - 6(I_t - I_1) - 2(I_t - I_1) = 0$. Multiplying as indicated, we get $16(I)_1 - 6(I)_t - 2(I)_t + 2(I)_1 = 0$. Collecting terms we get $24(I)_1 - 8(I)_t = 0$.

34. Now we instruct our computer to multiply both sides of this modified second equation by $\frac{3}{8}$, so we can subtract it from the first equation. We get $9(I)_1 - 3(I)_t = 0$, and subtracting this result from $50 - 3(I)_t - 16(I)_1 = 0$, we get $50 - 25(I)_1 = 0$. What is I_1? (2 ma) (4 ma) (8 ma)

35. Yes, and substituting back into our very first Kirchhoff's voltage loop equation, we get I_t is 6; then by using the Kirchhoff's junction current equation, we get I_2 is 4, and so on. This is quite easy, but if we program our computer for the general case, it will solve the hard problems.

36. You can see that any circuit can be solved by straightforward procedures, if enough information is available. With a circuit diagram and sufficient voltage and resistance, or current, values given, you trace the loops, applying Kirchhoff's Voltage Law, then set up the junction current equations, and solve for current and voltage.

37. Alternately, you may compute the equivalent resistances, adding the series values, and calculating parallel equivalents by the product over the sum. Consider this circuit. At the far right, the two 100-ohm series resistors make 200 ohms; in parallel with 200 ohms, they are equivalent to 100 ohms, which in series with the 100-ohm resistor above them make how many ohms for the entire right side series-parallel network? (200 Ω) (800 Ω) (2,000Ω)

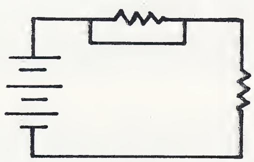
38. Yes. On the center series-parallel network we have the two 200-ohm parallel resistors which equal 100 ohms, in series with 100 ohms, to total 200 ohms. When we combine this 200 ohms in parallel with the right side network of 200 ohms, what do we have? (100 ohms) (240 ohms) (400 ohms)

39. Yes, and in series with the top 100 ohms, we have 200 ohms total equivalent, for one ampere total current. What do we do now? (Apply Ohm's Law for voltage drops and Kirchhoff's Current Law at junctions only.) (Apply voltage equations around individual loops only.) (either way)

40. Right. In previous discussion, we have often referred to the negative power supply terminal as a convenient voltage reference point. In fact, any point can be chosen and if it is not the most negative, or most positive point in the circuit, the voltage polarity must be very carefully noted. In many devices, the metal chassis is a common ground point and it is often the most negative voltage point. In this case, what would you say about a component connected to the chassis? (It's grounded.) (It's floating.)

41. When a circuit which is intended to carry current is "broken" so that it stops carrying the flow of current, it's said to be "open." This may be caused by a faulty component or an open switch or fuse. An ohmmeter can determine the point of open circuit by an infinite resistance reading across it.

42. When a component has an accidental great reduction in resistance or two conductors accidentally connect, this is called a "short circuit." As you can imagine, this may apply excessive voltage to another component which is not rated for so much power, and burn it out. Circuits are usually protected against damage by fuses or circuit breakers, which burn out or unset to open the power circuit. Which of these is a short circuit?



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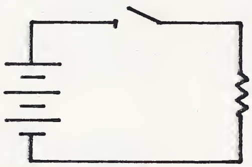

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BASIC ELECTRICITY Reference Folder Pe 8

Bridge Circuits and Divider Networks

1. In your previous study of direct current circuits, you have found that current and voltage may be divided by various arrangements of resistors in series and parallel. Certain series and parallel resistor arrangements are particularly useful for measurement and control purposes. These are called bridge and divider circuits.

2. There are a great many special kinds of bridges and dividers, but most of them are based on the "Wheatstone" bridge, named for English physicist Charles Wheatstone. It is essentially a simple series-parallel arrangement of four resistors in two series pairs connected in parallel.

3. One of the four resistors is variable, or adjustable. The junction points of each pair of resistors are connected to a sensitive meter or indicator with a reversible or zero-center scale. If all four resistors were exactly equal in resistance, what would the meter indicate? (half the current) (half the voltage) (zero)

4. Right. This would be considered the "balanced" condition. If the variable resistor (or "rheostat") were to be decreased in resistance, the bridge would become unbalanced, and the meter would indicate some non-zero value until, for example, the resistor connected to it, in the other parallel branch, were reduced exactly the same amount. What is this circuit called? (balancing bridge) (Wheatstone bridge) (Whitehead Divider)

5. Yes. In the basic Wheatstone bridge, shown here, one of the resistors, R_1, for example, in each of the two parallel branches is fixed in value, and equal to the corresponding resistor in the other leg or R_2. The variable resistor, or R_4, is precisely calibrated by a dial, and the corresponding resistor in the other parallel leg, R_3, may be unknown in resistance value. When the bridge is balanced so there is no deflection of the meter, what does the variable resistor dial reading signify? (only the setting of the variable resistor) (only the value of the "unknown") (both)

6. Right. Remember, if there is no deflection, the bridge is balanced and corresponding resistors are equal. When the total series resistance in each parallel leg is equal, and when one resistor's value is the same as the corresponding resistor in the other branch, or leg, then the value of two other resistors are equal to each other, and the voltage at the two internal series junction terminals is identical.

7. In the basic Wheatstone bridge, the use of the two fixed, equal, and corresponding resistors requires that the variable and unknown resistors must be exactly equal to balance the bridge. This is satisfactory when the unknown resistor has a value near to the upper value of the rheostat, but when it is only a small fraction of the rheostat's full value, or when it exceeds the maximum value, a ratio bridge may be used.

8. In the "ratio" form of the Wheatstone bridge, the unknown resistor is in the same series leg or branch as the variable resistor. In the other series leg, the two resistors may be any values, if the ratio of their resistances is known. This establishes the portion of the applied voltage which appears at its internal junction, which, for balance, must be the same as the voltage at the junction between the unknown resistance and the variable resistor. Think about this before you go on.

9. A ratio bridge has the reference ratio leg made up of 3000-ohm and 1000-ohm resistors. An unknown

resistor is placed in the other series leg, corresponding to the 3000-ohm resistor. The variable resistor reads 2000 ohms, at balance. What's the unknown resistor? (2000 ohms) (3000 ohms) (6000 ohms)

10. Right. The ratio of resistors in one of the branches must be the same as the resistor ratio in the other, at balance. If the reference ratio resistors are 400 and 100 ohms, and the others are, respectively, the unknown and 600 ohms, what is the unknown? (2400 ohms) (6000 ohms) (4000 ohms)

11. Another way of expressing the ratio bridge relationship is to state that when the voltages at the internal junctions are equal, the 2 sets of corresponding current-resistance drops are equal. This means that $I_1 \times R_1$ divided by $I_1 \times R_3 = I_2 \times R_x$ over I_2R_4. We can cancel out the currents in each fraction, and obviously the ratios of the resistance pairs are equal.

12. Once we realize the resistance ratios are equal at the balance adjustment, we can solve for the unknown resistance. Simply stated, it equals the adjustable resistance × the ratio of the resistors in the other leg.

13. What's the value of an unknown resistor in a bridge when the adjustable rheostat is 2500 ohms and the ratio of the other leg is 5 to 1? (1000 ohms) (5000 ohms) (12,500 ohms)

14. Voltages of several different values are frequently required for electronic devices which are operated from a single main power supply. In electronics, the communication and signals are usually at relatively low power level, so that power efficiency is not very important. For this reason, it is practical to subdivide the supply voltage by resistive networks.

15. These voltage-divider networks are analyzed and designed by circuit-analysis formulas, such as Ohm's Law and Kirchhoff's Laws. A simple series circuit of resistors across the main power supply would, of course, provide no-load voltages at the junctions as determined by the total current and Ohm's Law. But what other factor requires consideration? (The current supplied to loads would affect divider voltages.) (The overall voltage would tend to vary the series resistances.)

16. Yes. This would then require Kirchhoff's Law analysis. We would need to know, for example, the required load current and perhaps the voltage for each of the voltage levels at which loads are connected. For example, if we had a 24-volt supply and connected two 2000-ohm resistors across it, we'd have 12 volts at their junction with no load. But if we supplied 2 milliamps from this junction to a load, what do you think the voltage would be at this point? (10 volts) (12 volts) (14 volts)

17. Yes. This is why. The current through the top resistor, I, is the sum of the current through the lower divider resistor + 2 milliamps. The entire supply voltage is thus: the top resistance of 2K-ohms × (I_1 + 2 mils), + the lower divider resistance of 2K × I. Is this the equation representing the supply voltage? (yes) (no)

18. Yes. So if the voltage, 24 volts, after collecting terms = $4(I_1) + 4$, then I_1 is 5 milliamps and the junction voltage is what? (8.33 volts) (10 volts) (12.5 volts)

19. Yes, still 10 volts. You recall that we can work for convenience in electronics with K-ohms and milliamps to get volts, as well as ohms and amps in the regular Ohm's Law relationship.

20. You may wonder why, if we know what the current to each connected load at each divided voltage is, that we don't just use a series voltage-dropping resistor to achieve the desired lower voltage. Sometimes this is done, but you can see that if the load is disconnected, the voltage at the junction will rise to the full supply voltage, and if part of the load is disconnected, the remaining load will be supplied a much higher voltage.

21. For this reason, the lower voltage-divider resistors are used to "bleed off" a certain part of the total current, to provide a limited stability to the voltage taps. What do you think we often call these lower divider resistors? (drooling resistors) (sagging resistors) (bleeder resistors)

22. Right, and the current through them which is not supplied to any load is called the bleeder current. Here is a voltage divider circuit which requires two tapped voltages, 100 volts at 12 milliamps and 60 volts at 10 milliamps, with another 20 milliamps flowing as bleeder current. The total voltage supply is 120 volts. What are resistors A, B, and C to obtain these voltages? First, let's add up the currents, using Kirchhoff's Law.

23. The bleeder current through resistor A is given as 20 mils. Since the current through the divider resistor B is 20 mils plus the 60-volt load current of 10 mils, it totals 30 mils. The current through C is this 30 mils plus 12 mils more, or 42 mils. And the voltages across the dividers are 60, 40, and 20, respectively. Now how do we find the divider resistances? (Use Ohm's Law: $R = \frac{E}{I}$) (Divider Power: watts/amps)

24. Yes. Divider Resistor A is 60 volts, divided by the given 20 mils, or 3 K; Resistor B is 40 volts over 30 mils, or 1.33 K; and Resistor C is 20 volts over 42 mils, or.......what? (476 ohms) (47.6 K) (4.76 meg)

25. Yes. Before we go on, we should remember to compute the power dissipated in the divider resistors, so we will know what power rating we must specify for making the circuit, or replacing a resistor. By now we know the voltage, current, and resistance. Which formula would be used to calculate power? ($P = \frac{I^2}{R}$) ($P = E^2R$) ($P = EI$)

26. Right. In resistor A the power is 60 volts times 20 mils, or 1.2 watts; in B, it's 40 volts times 30 mils, or 1.2 watts and in C, it's 20 volts times 42 mils. What's that? (42 milliwatts) (840 milliwatts—.84 watt) (84 watts)

27. Yes. Sometimes we may design a voltage divider and wish to know what exact voltages we will get. If we have a divider like this one, with 2000, 3000, and 4000 ohms in the divider, carrying respectively, the bleeder current, 5 mils plus the bleeder current,and 9 mils plus the bleeder current, what voltages do we supply the loads? We can write the equations for total applied voltage, 78 volts. Which of these would it be? [$78 = 2(I_b) + 3(I_b + 5) + 4(I_b + 9)$] [$78 = 2(I_b + 10) + 3(I_b + 10) + 4(I_b + 10)$]

28. Yes. When we collect terms, we get $78 = 9(I_b) + 51$, which is $9(I_b) = 27$. What is the bleeder current I_b? (2.2 ma) (3 ma) (4.5 ma)

29. Yes. And 3 milliamps times 2K ohms gives 6 volts for the R_1 load; 8 mils times 3K ohms is 24 volts more, or 30 volts for the R_2 load. 12 milliamps through 4K ohms is 48 volts more to double check one total of 78 volts from the power supply. Now double check these figures before you go on.

30. The voltage divider circuits you've just studied had a common negative point, or "ground". Occasionally, it is necessary to provide an additional voltage which is further negative than the common reference ground. This could also be supplied by a voltage divider network, like this one.

31. Notice in this circuit that even though there may not be a dropping resistor in the positive lead, any load connected directly to the positive lead will draw current through the negative power supply lead, as well as the other leads in the divider network. In this case, also, the negative lead resistor carries the total of all of the load currents, plus the bleeder current through the lowest voltage divider resistor.

32. In this circuit, we have divider resistors from the positive terminals of 5K, 5K, 10K, and 2K, respectively. If the loads are 2, 4, and 6 milliamps, what are the voltages? First, we use Kirchhoff's Current Law, and see

that the smallest divider current, the bleeder current (I_b), flows through the 10K resistor, and the highest divider current flows through the 2K resistor, which is below ground. What is this current? (I_b + 10) (I_b + 12) (I_b + 15)

33. Yes. The overall voltage equation can be written at once, since the applied voltage, 170 volts, equals (2 times [I_b + 12]) + (10 times I_b) + 5 times (I_b + 6) + 5 times (I_b +10). What do we do next? (Multiply as indicated, collect terms) (Transfer voltages, invert, and divide.) (Offset resistances, subtract sums.)

34. Yes, we get voltage components due to the bleeder current times the entire 22K of divider resistors, plus the voltage due to the various load currents through the respective divider resistors. These add up to 104 volts, which when subtracted from the 170 applied volts, leaves 66 volts due to bleeder current through the 22K divider resistors. Now, what's the bleeder current? (2.2 ma) (3 ma) (4.4 ma)

35. Yes. This means that there's 15 mils through the 2K resistor below ground, only 3 mils through the 10K divider resistance, 9 mils through the next 5K resistor and 13 mils through the top 5K resistor. From the top, what are the power supply voltages, referred to ground? (+170V, +105V, +60V, -20V) (+140V, +75V, +30V, -30V)

36. Right. What power rated resistors should we use in each position? [.845W (1 watt); .405W (½watt); .060W (½ watt or less); .450W (½ watt)] [65V - 13 ma; 45V - 9 ma; 30V - 20 ma; 30V - 15 ma] [1.35W (2 watts); .945W (1 watt); .060W (½ watt); .315W (½ watt)]

37. Yes. Using Ohm's Law, we could, of course, calculate the equivalent load resistance at each voltage supply point, since we know the voltage and the current supplied to the load. The load, however, would probably consist of some complex circuit containing a number of resistors and semiconductors. If each load were just one resistor, how would we find it? ($R = \frac{E}{I}$) ($R = EI$)

38. In voltage dividers, remember that Kirchhoff's Voltage and Current Laws are to be used, depending upon what data is given and what are desired since the divider and load network is essentially a multipath, series-parallel circuit. If you sometimes enjoy working out a simple topological puzzle, this sort of analysis should not be difficult. You begin with what you know.

39. In the case of bridges, we have a balancing divider which in effect "subtracts out" the expected voltage value, and displays the out-of-adjustment voltage only, which exaggerates or emphasizes its effect somewhat like an expanded-scale voltmeter, to allow precision adjustment.

40. You will frequently find it necessary to design or work with circuits which divide or balance out D. C. voltages or signals. In the next eight programs, you will learn about alternating current electricity. Good luck!

BASIC ELECTRICITY Reference Folder Pe 9

Magnetism and Electromagnets

1. You are familiar with magnetic devices in common use, such as the permanent magnets on cabinet doors. Magnetism is a force which attracts one of earth's most common metals, iron, and to some extent, nickel and cobalt. Mixtures of these metals and other forms of iron, such as steel, are also attracted by magnetism. Does a magnet attract wood? (yes) (no)

2. An iron or steel rod, or even a needle, is usually magnetized so that it has the strongest magnetic attraction at the ends, and none at the center. The ends are called "poles," and if the magnet is suspended freely, it will line up, like a compass needle, with the north-south direction of the earth's magnetic field. The end of the magnet which points to the north is called the magnet's north pole, and the opposite end, the south pole.

3. Like the earth's magnetic field, a smaller magnetic field exists around a bar magnet. It can be represented by imaginary lines. The magnetic force acts along these lines, which can be considered to run from the north pole, around the magnet, entering the south pole and then it goes through the magnet itself. If you placed a magnetic compass in the field of a magnet, how would its needle line up? (along the lines of the magnet's field) (across the lines of the magnet's field)

4. Yes. Somewhat like an electrical circuit, which is the path of the current, a magnetic circuit is the path of the magnetic lines of force. Most magnetic circuits are made up of iron or the other magnetic materials which confine, control, and conduct the so-called "magnetic flux."

5. "Magnetic flux" is the term used to describe all the lines of magnetic force in the magnetic circuit, and is somewhat like the current flow in an electric circuit, except that there is no actual movement of matter in the magnetic field.

6. The distribution of the imaginary magnetic lines of force in a magnetic field can be inferred from the pattern of sprinkled iron filings or powder, on a sheet of glass or cardboard. The lines of force are continuous loops, never crossing each other, and those in the same direction seem to repel each other, spreading out evenly. Otherwise, the lines take the shortest path possible, in any given material. In iron, they can be more condensed than in air or other non-magnetic substance, but magnetic lines can, to some extent, pass through any material. Is there movement of particles in a fixed magnetic field? (yes) (no)

7. The number of lines of magnetic force per unit area across the lines is called "flux density," expressed in lines per square inch, or per square centimeter. Usually, the letter "B" is used to represent flux density. What is the magnetic flux? (lines of force in the magnetic circuit) (fluctuating magnetic particles in motion)

8. If you put two bar magnets together, you would find that in one arrangement, two pairs of poles would attract each other, and when they're reversed, they would repel each other. You could suspend one by a thread and it would line up north and south. If you did the same to the other magnet, you would find by moving the magnets together that the two north-seeking poles would repel each other, and a north-seeking and a south pole would attract each other.

9. The attractive or repelling force between two magnets is approximately proportional to the strength of each of the magnets, which means proportional to the product of both. It is approximately inversely proportional to the square of the distance between the attracted or repelled poles. Which pairs of poles would be attracted? [like s–s) poles] [unlike (n–s) poles] [like (n–n) poles]

10. Two magnets of equal strength, when their unlike poles are 10 centimeters apart, attract each other with a force of 100 dynes. Two other magnets, each of which are twice as strong as the first pair, are placed 10 centimeters apart. What's their attractive force? (100 dynes) (183 dynes) (400 dynes)

11. The first pair of magnets, which attract each other with 100 dynes of force when 10 centimeters apart, are now placed 5 centimeters apart. What is their attractive force? (100 dynes) (300 dynes) (400 dynes)

12. We can say there are three laws or rules of magnetic attraction and repulsion: first, unlike poles attract each other; second, like poles repel each other; and third, the forces involved are proportional to the product of the two magnets' strength, and inversely proportional to the square of the distance between the poles.

13. There is no known way of insulating against a magnetic field, since its lines of force will go through any material. But since some materials, like soft iron, can carry magnetic flux more easily than air or non-magnetic materials, it can be used as a sort of shield, which can be placed around devices which need to be protected from magnetism. This shield deflects the lines, and carries the field around the protected space.

14. "Ferrum" is Latin for iron, and since iron is the principal magnetic material, ordinary magnets are made of so-called "ferromagnetic" materials, usually iron or steel, and often in combination with nickel and cobalt. Alnico is a powerful, permanent magnetic material made with aluminum, nickel, and cobalt, which can lift 500 times its weight.

15. Magnets are made in various shapes for different purposes. Straight rod or bar magnets are mostly used for demonstrations, as in schools. Most magnets are found in a curve, like a horseshoe, so the distance between their poles is reduced and the part of the field through the air is shortened. Even magnets in the form of slabs or blocks usually are used with iron elements which turn the magnetic field back around. What is one kind of common magnet shape? (horseshoe magnet) (corkscrew magnet)

16. Permanent magnets can lose their magnetism as a result of heat, shock, or vibration. It is a good idea to avoid these conditions, and store magnets with a soft iron "keeper" bar across the poles, or in pairs with the attracted poles together.

17. You can make a piece of iron somewhat magnetic by aligning it north and south and striking it. Or more strongly, by hitting it when it's near a strong permanent magnet. But most often, temporary and permanent magnets are formed by placing them in a strong magnetic field formed by electric current flowing through a coil of wire.

18. In fact, the flow of electric current always produces some amount of magnetism, and a magnetic field can influence the flow of electric current. This is most visible today in television picture tubes, where the beam current is rapidly swept back and forth by a varying magnetic field. What would you think this basic relationship of electricity and magnetism is called? (electromagnetism) (electromagic) (magnetohydrodynamics)

19. Yes. Electricity can be generated by electrostatic means, by chemical means in batteries, by pressing crystals, and otherwise, but by far, the most common way of generating electrical power involves rotating electro-

magnets in generators. This is based on what facts? (Electric current flow produces magnetism; magnets influence current flow.) (Magnets are better insulators.)

20. Yes. You can see the way in which current produces a magnetic field by placing several compasses on a sheet of cardboard and placing a wire vertically through the sheet, and connecting it to a battery cell. The compass needles will all point in a circle around the wire.

21. If the end of the wire at the top is connected to the positive terminal of the battery cell, and the bottom to the negative, the current flow, or at least, the electrons, can be said to be moving upward from the negative to the positive terminal. Looking down at the compasses, we can see the north poles all point in a clockwise direction. If the current were reversed, the compass needles would reverse.

22. If you wish to remember this relationship, use your left hand. When your left thumb is up, representing electron or electric current flow, your fingers represent the way the compass needles' north poles point. When your left thumb is down, or left, or right, depending on current direction, your fingers indicate the magnetic field direction.

23. In the section of the wire carrying current upward, what is the direction of the magnetic field? (clockwise, looking down) (counterclockwise, looking down)

24. Yes. Here is a diagram of two wires carrying current. The one with the dot in the center, like the point of an arrow, is carrying current upward. The other one, with the cross, representing the tail of an arrow, carries current downward. Since between the wires the lines are in the same direction, they repel each other and are evenly spaced. The wires tend to be pushed apart.

25. Here is a diagram showing two wires, both with current flowing downward. The magnetic fields tend to combine, and the wires are attracted together.

26. What is the force between two parallel adjacent electrical conductors carrying current in opposite directions? (attract each other) (repel each other)

27. Right. What's the force between conductors with current in the same direction? (attract each other) (repel each other)

28. Yes. Of course, electromagnets are rarely formed by one or two conductors. They use a coil of wire, each turn of which conducts current which helps create a strong magnetic field. You can see that when a conducting wire is formed in a turn, a magnetic field is created in and around it, and when a coil of wire made of many turns of wire in series conducts electric current, a strong magnetic field is created.

29. You can use your left hand to remember how to find the polarity of the magnetic field of a coil of wire conducting current. If your fingers represent the direction of the current, or electron flow, your left thumb points to the north pole of the field inside the coil.

30. Here is a coil carrying DC current, which flows from the negative to the positive terminal. Which end is the north pole of the magnetic field? (left end) (right end)

31. This vertical coil is connected to the negative terminal at the bottom right and the positive at the top left. What is the magnetic polarity at the top of the coil? (north) (east) (south)

32. The strength of an electromagnetic field depends upon the current in the coil, the number of turns in the coil, the magnetic properties of the core, if any, and to some extent, on the shape of the coil, especially if it is rather long and thin. The more turns and current, and the more iron in the core, the greater the flux is in the field.

33. The quality of the core material which allows a coil to produce more flux than just air is called magnetic permeability. Something which is permeable to fluids is like a sponge, which lets them flow through. Magnetic permeability is somewhat like this, except that in this case, you must remember that air or a vacuum is not very permeable to magnetic flux. For example, soft sheet steel makes a better core for an electromagnet, than, say, cast iron, because magnetic lines of force are more easily established in it.

34. What is the name for the quality of soft iron which allows a greater magnetic flux? (permanence) (permission) (permeability)

35. Right. The permeability of air is 1, and wood, copper, and brass are about the same. The permeability of soft iron is many times as great. However, it is not as high when it is in extremely strong magnetic fields. This may be considered a form of "saturation" of the core material. For this reason, more iron is needed in devices like motors and transformers which use greater amounts of electric power.

36. The magnetizing force of an electromagnet coil primarily depends on amperes of current and coil turns. In a coil, a certain number of ampere turns will create a magnetizing force measured in "Gilberts," denoted by the letter "H." The flux density, you recall, is "B."

37. In magnetic circuits, there is a relationship, somewhat like Ohm's Law, which expresses the way magnetic flux is affected by the magnetizing force and the magnetic "reluctance" of the magnetic circuit. It is known as "Rowland's Law." It is: the Greek letter "Fee" or "Fi," in maxwells of flux, equals H, in Gilberts of magnetizing force, divided by R, in "rels" of magnetic reluctance. Reluctance is affected by the amount of iron and its shape and permeability.

38. Reluctance in rels equals the core length "L" divided by "A," the area of the core times mu which stands for permeability. You may remember that permeability equals B over H; or flux density divided by the magnetizing force.

39. The magnetic material is considered to be made up of small molecules of iron or other metal which are themselves tiny magnets and are lined up, or "oriented" first one way, and then the other, as magnetic forces are applied. These molecules are referred to as domains. As the force is removed, however, the magnetic flux in the material does not fall to zero. Instead, the material retains a large amount of the magnetic flux induced.

40. This concept can be shown on a hysteresis curve. This curve shows the changes in magnetic flux strength, B, with the changes in magnetic force, H. Point A shows the maximum amount of magnetic flux achieved with the greatest application of force. Point B shows the amount of magnetic flux retained after the magnetizing force is withdrawn.

41. When the current and magnetizing force are reversed, the domains are reversed in direction. Consequently, the flux is reversed and is shown by the downward sloping line which ends at C. When the force again is withdrawn and then reversed, the flux again undergoes a similar lag to point D, and then rapid rise to the maximum at A.

BASIC ELECTRICITY Reference Folder Pe 10

Alternators and Alternating Current

1. The first kind of electrical energy which was used by experimenters and scientists came from electrostatic or electrochemical sources, and had a fixed polarity. The so-called voltaic cells, and batteries made up of these chemical cells, provided Direct Current power, generally of low voltage.

2. What do we call the kind of electrical energy, such as obtained from batteries, which has a single fixed polarity with designated positive and negative terminals? [Alternating Current (AC)] [Base Current (BC)] [Direct Current (DC)]

3. Right. Electrical power, however, can be transmitted by a current which periodically switches from one direction to another, somewhat like a piston on a crankshaft, as compared to a one-directional flow, like water over a water-wheel. This sort of power, which alternates its direction of flow and polarity is called what? (alternating current—AC) (base current—BC) (direct current—DC)

4. Yes. Alternating current has, for the past century, had a number of advantages over direct current for generation and transmission. New developments in plasma flow, fuel cells, solid state devices and high-voltage DC transmission may in the future offset some of the advantages of AC, but it will be the principal means of power distribution for some time.

5. First, most electrical power is at present generated from burning gas, oil products, or coal, and using mechanical shaft energy. Even nuclear and hydroelectric plants generally go through this step. Because the induction of electrical power by a coil passing a magnet naturally tends to reverse itself as it passes the magnet, it is simpler to generate electrical power in AC form than DC, which requires a switching commutator or rectifier.

6. Second, for the past century it has been cheaper and easier to transform the voltage of electrical power from low voltage to high voltage and back again using simple electromagnetic transformers instead of DC devices. Since there is less energy loss in transmitting power at high voltage, but more safety and convenience in using it at a lower voltage, the easy change of AC voltage by transformers has made it the preferred type.

7. Which is easier to generate with a rotary electromagnetic generator? (AC) (DC)

8. Which is simplest to transform in voltage level for power distribution? (AC) (DC)

9. As you learned in the previous program, voltage and current can be induced by moving a magnetic field into or across a single conductor, or a coil of conductors. Conversely, a magnetic field can be created by conducting electric current through a wire conductor, or a coil.

10. The combination of one coil of wire connected to a voltage source and another coil nearby connected to some output circuit is called a transformer. A transformer has no moving parts at all. A transformer will work continuously only if the input voltage and current vary or alternate continuously. This is because the induced voltage on the second coil is due to the change of the magnetic field, not its steady value. Transformers are primarily for what kind of current? (AC) (DC)

11. A really effective transformer needs a strong magnetic field, so a soft iron core for the two coils is nearly always used for electric power transformers. The core is shaped to provide a complete magnetic circuit in the most convenient shape, usually in a sort of figure–8, as shown here.

12. In addition to the sort of constant, steady alternating current used to supply electrical power, transformers may be used to transform alternating electrical signals, like voice or music, control code tones, or signals. Sometimes the alternating power input to the transformer also contains some direct current mixed with it, but the output of the transformer is always pure AC. At the bottom is the symbol used to represent a transformer.

13. How would you describe a transformer? (a rotating magnetic unit which generates AC instead of DC) (a non-moving assembly of two or more coils in a magnetic circuit, for changing voltage)

14. Right. Transformers may sometimes be heavy, because of the iron core and copper coils, but they are compact, silent, non-moving, and relatively efficient. A rotating AC generator, called an alternator, efficiently converts rotational mechanical energy to electrical energy. It also does this by electromagnetic induction, but instead of the output coil inducing the voltage by a changing magnetic field as in the transformer, the coil is rotated in a constant magnetic field so that the magnetic lines are alternating from one direction to the other.

15. If a wire is moved across the lines of a magnetic field, sometimes called "cutting" the lines, the wire will generate a small voltage. If one side of a coil with many turns is moved past a magnetic pole, a much greater voltage is generated. And if a coil is rotated in the space between two opposite poles, twice as much voltage is generated. Why does this happen? (by electrostatic charge) (by voltaic deduction) (by electromagnetic induction)

16. Right, when a loop or coil of wire is rotated past two magnetic poles, a voltage is generated, until the wires in the loop are between the poles, across them, at which time the wires are not "cutting" any of the lines of flux in the magnetic field. Would you think any voltage would be generated at that instant? (yes) (no)

17. Right, no voltage is generated. But as the coil continues to rotate, its opposite side goes past the magnetic poles, and a voltage of the opposite polarity to the previous voltage is generated. What is the name for a voltage which changes direction back and forth like this? [alternating current (AC) voltage] [direct current (DC) voltage]

18. Yes. The voltage doesn't increase from zero to its maximum all at once as the coil starts to

go by the magnetic pole. It builds up gradually in a sort of smooth curve which is related mathematically to rotation and circles. It's called a "sine" curve or wave. What branch of mathematics deals with "sines?" (arithmetic) (long division) (trigonometry)

19. This sine wave, in some ways, is the simplest and purest curve or wave there is. You will learn to recognize it instantly on a cathode-ray oscilloscope. If you heard it, it would be a pure, flute-like tone. It is the curve you would plot on a graph if the horizontal scale is in angular degrees of an angle and the vertical scale is the value of the sine of the angle.

20. The sine wave is about what would be drawn by the position of a piston varying with time or shaft angle, on a long connecting rod to a rotating crankshaft. Vibrating cables, wires, or strings are somewhat like sine waves, which can be considered "pure" waves, compared to square waves, saw tooths, or triangles, or complex waves.

21. There are several trigonometric ratios. One is the cosine, which is the ratio of the length of the side adjacent to an angle in a right triangle to the length of the hypotenuse. Another is the ratio of the side opposite an angle to the hypotenuse. What is this ratio called? (shine) (sine) (billboard)

22. Yes. Actually, the shape of the cosine curve is just like the sine curve, but it is "out-of-phase" with the sine. Notice that while the sine wave begins at zero, the cosine does not.

23. In a generator, the voltage generated will theoretically follow a sine wave if the magnetic flux is absolutely uniformly distributed, and the loop is compact. If there are just two magnetic poles, the rotating loop or coil will generate one "cycle" or complete period. During a complete cycle, the current flows first in one direction, then the other.

24. A two-pole generator with one coil turning in it 60 times per second would generate 60 complete cycles of AC voltage each second. Recently, the term hertz, (Hz) has been adopted to mean cycles per second, and we will use it in later programs. What is a way of describing a "cycle?" (a complete two-direction alternating wave) (part of a wave going in one direction up and down to zero) (any number of oscillations about a mean position)

25. Yes. How long does one complete 60 cycle-per-second wave take, or last? ($\frac{1}{120}$ second) ($\frac{1}{60}$ second) (1 second)

26. Yes. Each half-cycle of a 60-hertz wave takes only $\frac{1}{120}$th of a second, of course, and events which are not affected by the direction of voltage or current, like lighting some neon lamps, will occur 120 times per second. Remember, a complete cycle contains two half-cycles during which current flows in alternate directions. These half-cycles are sometimes called "alternations."

27. The time required for one complete cycle is called the "period" of an AC wave. The period of a 60 cycle-per-second (or 60 Hz) wave is, of course, $\frac{1}{60}$th of a second. What is the "period" of a wave in a 100 cycle-per-second AC voltage? ($\frac{1}{60}$th sec) (.01 sec) (100 seconds)

28. In a generator, if the loop, or coil, wound on an iron "armature," or "rotor" is rotated at a steady rate, the cycles of voltage generated will be constant and steady. This is the way most mechanical energy is converted to electrical energy. Most generators provide the strong continuous magnetic field by an electromagnet, rather than a permanent magnet. Some generators even rotate the electromagnetic field inside the AC generating coils. In either case, the "alternator," which is a name for an AC generator, needs only a pair of slip ring contracts, rather than the complicated switching commutator needed for DC generators.

29. What would be the frequency of the AC voltage generated by a two-pole single-coil alternator rotating at 50 turns per second? [50 cycles per second (50 Hz)] [60 cycles per second (60 Hz)] [100 c/s (100 Hz)]

30. Generators are sometimes designed with 4 magnetic field poles, that is, 2 pairs of north-south poles. In this case, an armature coil will generate two complete cycles, with four alternations or half-cycles, during each revolution. Big alternators sometimes have even more than 4 field poles, and more than 1 armature coil, so several full cycles may be generated per turn. An AC generator generates a frequency f in hertz equal to $P_2 R$, where P_2 is the number of field poles, and R is revolutions per second.

31. If a generator has two pairs of field poles and turns at 30 revolutions per second, what is the frequency of its voltage output? (30 Hz) (60 Hz) (120 Hz)

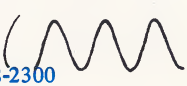
32. Yes. Of course, we can express 30 revolutions per second as 1800 RPM, and count each pole individually, instead of in pairs. In this case, we would say that $f = \frac{(P_1)(RPM)}{120}$ and call the generator a "four-pole" alternator instead of saying it had "two pairs" of field poles.

33. The voltage generated by an alternator is proportional to the magnetic field strength of the field magnets, proportional to the frequency generated, and also proportional to the number of turns in the armature coil winding. It could be expressed approximately as $V = .02\ \Phi f n$ where Φ is megamaxwells, f is hertz, and n is turns of wire in the armature coil.

34. Sometimes there are more than one set of armature coils offset at angles from each other. A common arrangement is with 3 sets of coils generating so-called "3 phase" AC voltage. The cycles of voltage in each coil set are synchronized, but not simultaneous; they overlap somewhat, so they must not be merely connected in parallel. In the next program, you will learn about phase relationships, and how vectors are used to work with them.

35. What would happen to the voltage in an alternator if you increased its speed of rotation? (Voltage would increase; frequency would decrease.) (Voltage would decrease; frequency would increase.) (Voltage would increase; frequency would increase.)

36. What is the frequency of the voltage from a single phase alternator with one pair of field magnet poles, turning at 3600 RPM? (30 Hz) (60 Hz) (120 Hz)

37. Which of these is a sine wave? () () ()

BASIC ELECTRICITY   Reference Folder   Pe 11

Alternating Current Analysis

1. You have learned that an alternating current periodically alternates its flow from one direction to the other. Alternators, which are rotary electromagnetic generators, generate voltage in a smoothly varying pattern as a result of the distribution of the strength of their magnetic field.

2. The shape of the voltage pattern is called a "sine wave," and the voltage level at any instant depends on the position or angle of the rotary armature at that instant. We say that the AC voltage has an amount, or amplitude, and a phase, or phase angle.

3. In your studies of mathematics for electronics, you have learned about quantities which have both amount and direction. What did you call such quantities? (victories) (vectations) (vectors)

4. Right. We can consider an AC voltage or current as a vector, too. For some purposes, like supplying power to a lamp, only the amount or amplitude of the voltage is important. But for comparing two AC voltages, or relating an AC voltage to the AC current through a non-resistive load, we will need to use the phase angles of the alternating current values.

5. Here is a way of relating the sine of an angle to the sine curve you will see in drawings and on the face of an oscilloscope tube. At the left is a circle which has a radius of one arbitrary unit. This radius is considered the hypotenuse of a right triangle having one side on the horizontal axis, and the other side, opposite the angle of the radius.

6. You will notice that as the angle increases counterclockwise from 0 to 30 degrees, to 60 degrees, and to 90 degrees, the length of the vertical side of the triangle, which is the same as the height of the curve above the horizontal axis, increases smoothly along the sine curve. What is the height at 30 degrees? (.2) (.5) (.8)

7. Yes. The sine of 30 degrees is 5 tenths, as is the sine of 150 degrees. And the sine of 210 degrees and 330 degrees is -.5. Mathematically, we could say that the voltage "e" at any instant equals its maximum value times the sine of the angle.

8. Its maximum positive value is at 90 degrees and maximum negative value at 270 degrees, while it is zero at zero degrees and what other angle? (45 degrees) (135 degrees) (180 degrees)

9. Right. There are 360 degrees in a circle, of course, but sometimes it is convenient to use the "radian" which is a unit of angular size containing 57.32 degrees. The length of the arc of a one-radian angle is exactly equal to the radius, which simplifies writing some formulas. There are exactly 2 pi, or about 6.28 radians, in a circle.

10. When we speak of the frequency of alternating current in hertz, which is complete cycles per second, we could also speak of 360 times that number in degrees of phase angle per second. We could also multiply the frequency by 2 pi to express the frequency as radians per second. This would be when we need to use the AC voltage or current as vector quantities for some reason. How would you describe a vector? (quantity with amount and direction) (amount of some quantity)

11. If your home is supplied with voltage of 60 cycles per second, this would be 60 times 360 degrees per cycle, or 21,600 phase angle degrees per second. How many phase angle radians per second would it have? (60) (60, 2 pi, 377) (21,600)

12. The phase angle Θ (theta) at any instant could be represented by the angular rate in degrees or radians per second times the time, t, which has elapsed since some starting instant. In the Greek letters used in formulas, "theta equals omega t," where omega is the angular rate. We can substitute "omega t" for theta as the angle, making the instantaneous voltage equal to the maximum voltage E_m times the sine of omega t.

13. If in your 60 cycle household electric outlets, omega is 377 radians per second, what would the phase angle be one-thousandth of a second after zero? [.001 times 377 (.377 rad.)] [.001 times 21,600 (21.6 rad.)] [.001 times 3600 (3.6 rad.)]

14. Yes. An angle of .377 radians, or about 22 degrees, would have a value of sin of about one-third, so a 180-maximum-volt supply, for example, would have risen to about 60 volts in one-thousandth of a second after crossing zero. Remember that a 60 hertz voltage completes a whole cycle in one-sixtieth of a second. For a voltage to rise and fall in a half cycle, one one hundred and twentieth of a second is required. How long does it take after zero for a 60 hertz voltage to reach the maximum value? [$\frac{1}{240}$th second (.0042 sec.)] [$\frac{1}{120}$ second] [$\frac{1}{60}$ second]

15. Yes. In a single cycle, the voltage crosses zero twice. How many times does it reach a maximum value in one complete cycle? (2) (4) (6)

16. Yes, once in one direction and once in the alternate direction. To avoid confusion, it should be pointed out that there are four ways that AC voltage may be designated: the instantaneous voltage, small e; the maximum voltage, E_m; the effective voltage, capital E; and rarely, the average voltage, E_{avg}. What is the designation of "effective voltage?" (e) (E_m) (E)

17. Right. The "effective voltage" is the value for the AC voltage which is effective and useful in determining the power consumed by a light bulb, or an electric range element. Obviously, the total current flow and power consumed by these loads won't be solely related to the very maximum voltage, or for that matter, to zero, which the voltage crosses twice each cycle, but to some value inbetween.

18. The first thought which occurs to us is that the effective voltage should be just the average voltage; that is, the average absolute value of all the instantaneous voltages which are determined at various points in time. This turns out to be not quite true, because you will recall that power used is related to the square of the voltage. For this reason, the effective voltage is the square root of the average values of the squares of the instantaneous voltages. Not quite the same!

19. What's a definition of the "effective" AC voltage, E? (voltage related to power use; square root of average voltage squares) (voltage effective in controlling impedance saturation)

20. Yes, effective AC voltage can be described that way, no matter what shape the AC voltage curve is. For example, let's take an alternating voltage in the shape of a square wave, which goes from, say, 10 volts in one direction, then instantly switches to 10 volts in the other direction. In this case, the maximum voltage is 10 volts; the instantaneous voltage is always 10 volts and the average absolute voltage is 10 volts. What would the effective AC voltage be? (8 volts) (10 volts) (12 volts)

21. Yes. That's easy to see, but if you had a triangular shaped wave with a maximum or peak absolute voltage of, say, 20 volts, and an average of 10 volts, and instantaneous voltages of anywhere between 0 and 20 volts, the effective voltage would be the square root of the average of zero squared, 10 squared, and 20 squared. This is the square root of $\frac{500}{3}$, or about 12.9 volts.

22. If you had a 100-volt square wave, what would the absolute values of the various voltages be? (E = 100 V; E_{max} = 200 V; E_{avg} = 120 V; e = 0 to 200 V) (E = 100 V; E_{max} = 100 V; E_{avg} = 100 V; e = 100 V)

23. Right. If you had a triangular AC voltage with an average absolute value of 100 volts, and a maximum value of 200 volts, what would the other voltages be? (E = 129 vac; E_{max} = 200 V; e = 0 to 200 V) (E = 100 vac; E_{max} = 100 V; e = 0 to 100 V)

24. Yes. But although square and triangular waves are geometrically simple to look at, they are really very complex waves in some respects. A sine wave is the natural result of rotary generators and the result of simple AC filtering and is generally considered a "pure" wave for most purposes. But would you guess, for example, that the maximum voltage is, say, twice the average voltage or twice the effective voltage? (yes) (no)

25. No, the maximum voltage of sine wave AC turns out to be 1.414 times the effective voltage. If you had 120 volts effective AC at a power outlet, which would be the maximum absolute voltage? (120 V max.) (about 170 V max.) (200 V max.)

26. Yes. Mathematicians use the word "mean" to signify "average." Since the effective voltage is equal to the square root of the average of the instantaneous voltages squared, it is also the square root of the mean of the instantaneous voltage squares, or, for short, the root of the mean of the squares or RMS. If you had a sine wave AC voltage with a maximum absolute value of 141 volts, what would be its approximate effective voltage? (E = 70 VRMS) (E = 100 VRMS) (E = 120 VRMS)

27. There is sometimes a fifth kind of AC voltage used for reference purposes on oscilloscopes. It's called "peak-to-peak" voltage. Its value, for any balanced AC voltage, is just twice the maximum or peak voltage. If the RMS voltage of a sine wave at some point is 100 volts and the maximum or peak voltage is 141.4 volts, what is the peak-to-peak voltage? (282.8 volts peak-to-peak) (200 V AC)

28. If you had an effective or RMS voltage of 100 volts in a sine wave pattern, the peak or maximum voltage is 141 volts. What do you think the approximate value of average voltage would be? (50 V) (90 V) (200 V)

29. Yes. For a sine wave pattern, the average voltage is about 90% of the RMS effective voltage, the maximum or peak voltage is 141% of RMS, and the peak-to-peak is 283%. The instantaneous voltage? Well, it's just the maximum voltage times the sin of the angle at the instant.

30. To change the point of reference; in terms of the maximum sine wave voltage, the peak-to-peak voltage is twice as much, the RMS is 70.7% as much, the average voltage 63.7%, and the instantaneous voltage is still E_{max} times the sine of the angle. If the maximum or peak voltage is 50 volts, what is the RMS voltage? (35.35 VRMS) (50 VRMS) (100 VRMS)

31. Yes. Since the most useful and commonly used form of voltage is RMS, or effective voltage, this is the AC voltage which is assumed to be meant whenever AC voltage is given without any qualifications.

32. You can readily see that if an alternating voltage is connected across a simple resistive load, the current

through it will vary directly and immediately with the voltage applied. This means there is a peak or maximum current, an effective or RMS current, an average current, an instantaneous current and a peak-to-peak current. In a plain resistor load, these current values will bear the same relationship to each other as the corresponding voltage values do.

33. The instantaneous current through the resistor will be zero and maximum at the same instant that the voltages are. This is said to be "in phase." This is because the current and voltage through a resistor follow what law? (Law of Survival) (U. S. Constitution) (Ohm's Law)

34. Right. Some voltages and currents are not in phase. If you had two rotary AC generators clamped to the same shaft, and one was slightly ahead of the other, it would always reach its zero and maximum values slightly ahead of the other. It would be said to be "leading" the second one, or the second one is "lagging" the first. They are slightly "out of phase" with a small "phase difference."

35. Two sine waves of exactly the same frequency can be in phase with each other, or out of phase, in which one is leading and the other, lagging. They may have equal or unequal amplitudes. But if the frequency is absolutely the same, two or more sine wave voltages can be combined, and oddly enough, the result is another perfect sine wave!

36. When two sine waves of exactly the same magnitude but which are totally out of phase, or 180 degrees out of phase are combined, the result is zero, but that's a special case. If you were to add 10 volts RMS at 60 hertz to 5 volts 60 hertz, and they were exactly in phase, you'd get 15 volts RMS. If they were 180 degrees out of phase, you'd get 5 volts. And if they were, say, only 20 degrees out of phase, you'd get a little less than 15 volts.

37. Now here is where your study of vectors will help. If you clamp together two identical rotary AC generators 90 degrees out of phase from each other, you'll find that the first generator is at its maximum voltage just as the second one is crossing zero, and so on. If they were connected, would they always cancel each other out? (yes) (no)

38. No, they would cancel out at 45 degrees, but at 135 degrees they would both be 70.7% of their peak value in the same direction, and connected together would add up to 141.4% of their individual peaks. Their vector sum would be a voltage equivalent to the hypotenuse of a right triangle, or the vector sum of two vectors from an origin, "O." Study this for a moment, then push the center button to go on.

39. When two sine waves are added, what do you get? (a square wave) (another sine wave; the vector sum of the two waves) (pneumonia)

40. What is the sum of two 10-volt sine wave signals at the same frequency, 90 degrees out of phase? (0 volts) (14.14 volts, at 45 degrees from each) (20 volts)

BASIC ELECTRICITY Reference Folder Pe 12

Inductance and Inductors

1. A lamp bulb, or a toaster, or a soldering iron are essentially resistors which convert electrical energy to light or heat. It makes little difference whether these resisting devices are connected to direct or alternating current supplies. Other kinds of electrical loads react differently, however, depending upon the nature of the current being supplied.

2. In the next 5 programs, you will learn that there are three kinds of electrical components—resistive, inductive, and capacitive. The inductive and capacitive components have an entirely different reaction to alternating current than to direct current. These two types, in fact, are called "reactive."

3. You have learned about electromagnetic induction in coils, transformers, and motors, so you won't be surprised to learn that such things display electrical "inductance," in addition to some resistance. We will say they have "inductive reactance" in an electrical circuit. Does inductance act the same in DC as in AC circuits? (yes) (no)

4. Right. When current passes through a typical resistor, it flows evenly, depending on the voltage, and the power into the resistor is all converted to heat, or possibly some light. But when direct current is applied to an electromagnet or transformer coil, some of the first energy which flows is stored up in the magnetic field. The electrical power produced is then converted mostly to heat after a fraction of a second.

5. On the other hand, if an electromagnet coil is connected to alternating voltage, more of the current is stored up in creating and reversing the magnetic field, and less is just turned into heat. This is because the current tends to lag behind the voltage, so the power which might be used is cancelled out, vectorially. What kind of electrical load is an electromagnet? (resistance) (capacitance) (inductance)

6. Right. Some things in nature and mechanics, (and probably you know some persons like this), are opposed to change, even if they finally go along with it. Inductance is like this. It is a characteristic of a circuit which opposes any change in current flow. It resists a starting surge of current when first connected to a voltage supply and it tends to continue any established current for an instant, even when the voltage is reduced. How would you describe this tendency? (leading) (resistive) (lagging)

7. Which of these is most likely to have inductance? (capacitor) (resistor, lamp, heater) (coil, electromagnet, transformer)

8. Right. The unit of inductance is called the henry for the American physicist, Joseph Henry, and is represented by the letter "h." An inductor has one henry if one volt is

induced when the current in the inductor is changing at one ampere per second.

9. Mathematically, it's said that the induced voltage equals the inductance times the rate of current change. This rate is written "delta i" meaning a small change in current, divided by "delta t," which means that the induced voltage is opposite in direction to the main voltage. If an inductor has 20 henries inductance, and the current through it changes two-tenths of an ampere in one-tenth of a second, what would be the induced voltage? (22 volts) (40 volts) (200 volts)

10. As we said, inductance is one of the three basic properties of electric and electronic circuits, and some small inductance is present in all circuits, even with short or straight wires. You'll remember that when a conductor is moved relative to a magnetic field, a current and voltage are induced. The current and voltage induced always run counter to the effect that produced them.

11. A coil of wire has more inductance if it is shaped compactly and wound, for example, in neat layers. This is because each section of wire coil is exposed to many more lines of magnetic flux. Secondly, the more turns it has, the greater its inductance. And thirdly, the greater the permeability of the core, the more inductance a coil has, at least until the core is saturated.

12. What factors will tend to increase the amount of inductance in an electromagnetic coil? (resistance, humidity, ductility) (coil compactness, number of coil turns, core permeability)

13. Right. As you learned, a magnetic core has more permeability if it is made of soft iron and has a complete, compact magnetic circuit. Which of these would have the most inductance?

14. If you connected this inductor to 10 volts AC, at 400 hertz, (cycles per second), would you say that the current would lead or lag the applied voltage? (lead) (lag)

15. Right. A millihenry is one-thousandth of a henry. A microhenry is a millionth of a henry. An inductor has 10 henries inductance because it has 500 turns in a compact coil placed on an efficient soft iron core. What would you guess is the inductance of a coil, with 100 loose turns on a ceramic spool, with air as its core? (.001 microhenry) (40 millihenries) (25 henries)

16. Yes. Every inductor has a certain amount of resistance in its wire coil, so in a circuit you will not find a pure inductance. Also, in most circuits there are resistances in the power source, and in other circuit elements and components. For this reason, we need to calculate what happens in real circuits which have both inductance and resistance.

17. This drawing shows the amount of current through an inductor when a DC voltage and resistance are first applied to it with the inductor and resistance then shorted by a switch. Notice that when the DC voltage is applied, the current gradually increases for a fraction of a second to the final value. When the voltage is removed and the inductor and resistance are shorted out, the current continues flowing, gradually decreasing for a fraction of a second.

18. The current increases or decreases in a non-linear way, that is, rapidly at first, then somewhat more slowly as it approaches its final value. Since in theory it never quite reaches that final maximum value, it is useful to choose a value like half way or 90% of the way there. The most useful value, it appears, is about 63%.

19. When an inductance of one henry is connected in series with a resistance of one ohm, the current reaches 63% of its final value one second after a fixed direct voltage is applied to them. The greater the inductance, shown as "L," the longer this time is. The greater the resistance, the shorter it is. The time constant of the circuit is equal to the inductance divided by the reactance.

20. The time constant of a circuit with 10 henries and 10 ohms is one second. Ten henries in series with 100 ohms has a time constant of .1 second, but if these were 10 henries and only one ohm, it would be 10 seconds before the current reached 63% of its final value. This would be an extremely low-resistance, high-inductance circuit.

21. What is the formula for the time constant of a resistance-inductance circuit? $(L \times R)$ $(\frac{R}{L})$ $(\frac{L}{R})$

22. This is an illustration of the self-induced voltage which occurs in an inductance when a DC voltage is intermittently applied. You can see that this voltage is the highest when the current is increasing or decreasing the most rapidly. The polarity of the voltage depends on whether the current is increasing or decreasing.

23. What kind of inductance would you guess causes a self-induced voltage, say in an inductor with one winding? (self-inductance) (mutual inductance)

24. Yes, self-inductance, but we often just say "inductance." Mutual inductance, however, occurs whenever two coils are quite near each other, especially if they share the same iron core, and if one coil is wound next to, or on top of, the other.

25. When mutual inductance exists, we can have a transformer, which is a device by which current through one coil-winding induces a voltage in the other coil. When does this occur? (when two coils are magnetically close-coupled) (when two coils are isolated from each other)

26. Yes. More mutual inductance exists when the coils are linked closely together and the magnetic flux is nearly completely shared. This is called "maximum flux linkage." For efficient operation you would wish maximum mutual inductance in what sort of device? (toaster) (lamp) (transformer)

27. The mutual inductance in henries between two coils, say L_1 and L_2, is equal to the square root of their product, if the coupling is perfect. Two coils each of 10 henries would have 10 henries of mutual inductance represented by M, if completely coupled. A coil of 10 henries perfectly coupled with a coil of 2.5 henries would have a mutual inductance, M, of 5 henries, since the square root of 25 is 5.

28. Nothing is perfect, however, If the magnetic flux linkage, represented by the magnetic coupling coefficient K, is only .5, the mutual inductance of two 10-henry coils is only 5 henries, since M is K times the square root of L_1 times L_2.

29. What is the mutual inductance of 2 coils, one of 10 henries and one of 4.9 henries, with a coupling coefficient of .5? (1.4 henries) (3.5 henries) (7.0 henries)

30. You have already learned that 2 resistors in series have the sum of these resistances as total resistance, while 2 equal resistances, for example, combine in parallel to half of each resistance. Inductors can be combined in series and parallel, too, under certain conditions.

31. When 2 or more inductors are located far enough apart from each other so that there's no significant mutual inductance, or when they are effectively shielded from each other, their inductances are combined like resistors, added in series, and inverses added when parallel.

32. An inductor of 80 millihenries is connected in series with a separated and shielded inductor of 60 millihenries. What is their combined inductance? (60 mh) (80 mh) (140 mh)

33. Right. When 2 inductors share the same core or magnetic field either completely or partially, their inductances can't just be added, or paralleled, without considering their mutual coupling. The total inductance of two partially coupled inductors is their sum, plus or minus twice their mutual inductance. The doubled mutual inductance is added when the inductances aid the common magnetic field; it is subtracted when they oppose each other.

34. Two inductors, each of 10 millihenries, have a coupling coefficient of 0.8. When they are connected in series so that their fields are aiding each other, what is the total inductance? (20) (36) (40)

35. Yes. Sometimes two similar coils are arranged so that one coil can be moved or rotated with respect to the other. This will constantly change the value of K and provide for a total series inductance which moves from almost zero to nearly four times the mutual inductance.

36. When inductors are not coupled at all, and instead are connected in parallel, their combined inductance is calculated like paralleled resistors. For example, the combined inductances of two separated 50-henry inductors in parallel is 25 henries.

37. You can figure the total inductance of parallel separated inductors by taking the sum of their inverses. That is, the inverse of the total inductance equals the sum of the inverses of the individual inductances, or $\frac{1}{L_{total}} = \frac{1}{L_1} + \frac{1}{L_2}$, etc.

38. What is the combined inductance of 2 separated inductors connected in parallel, one of 100 millihenries and one of 50 millihenries? (33.3 mh) (75 mh) (150 mh)

Inductive Reactance

1. In the last program you learned that when a DC voltage is connected to a coil, the inductive reaction effect on the current occurs at the instant of connection, but after a very short time, the current is limited only by the resistance of the coil and any other resistance in the circuit.

2. When an inductance is connected to an AC voltage, however, its reaction affects every alternation of the voltage, so its effect is greater, for it is continuously creating and reversing a magnetic field. As you learned, this action induces a voltage in the coil which tends to oppose the change in the current's direction and amount.

3. If the AC voltage applied to an inductor is sinusoidal or a sine wave, the current is sinusoidal too and lags the applied voltage by 90°. If the current is sinusoidal, the self-induced voltage in the coil is sinusoidal too and, in turn, lags the current by another 90°. What is the phase angle between the applied voltage and induced voltage? (135.6°)(180°)(206.8°)

4. Yes, so the induced voltage actually opposes the applied voltage. This self-induced voltage may be considered to be the cause of, or at least a corollary of, the inductor's tendency to oppose or limit the amount of alternating current through it, even though its resistance may be very low.

5. This opposing induced voltage in inductors is sometimes called "counter-EMF" or "back-voltage." It lags the applied voltage by 180°. How much does it lag the current? (45°) (90°) (135°)

6. When a resistor opposes or limits the flow of either AC or DC current, as voltage is applied to it, we call this "resistance." When an inductor opposes or limits alternating current as AC voltage is applied to it, we call this "reactance." Reactance in this respect is like resistance, and can be vectorially added to resistances, but, of course, it's certainly not the same thing!

7. What is the name for the tendency of an inductor to limit or oppose the amount of alternating current through it? (inductive reactance) (capacitive reactance) (resistance)

8. Yes. Inductive reactance depends on the inductance in henries and the frequency, in hertz, or cycles per second. The reactance in ohms equals 6.28 times hertz times henries, or exactly 2 times pi times hertz times henries. What would be the reactance to 60-hertz voltage of a two henry inductor? (120 ohms) (240 ohms) (753.6 ohms)

9. Right. What is the reactance of a 100-millihenry (that's $\frac{1}{10}$ of a henry) inductor at 400 cycles per second? (251.2 Ω) (628.4 Ω) (1400 Ω)

10. Yes. We can derive the formula by noting that the inductive reactance, X_L equals the

back voltage divided by the current, and that the back voltage, or "induced counter-EMF" in the inductor, equals 2 pi f × the inductance L × the current I. Combining these expressions, the voltage and current cancels out, and we have X_L is 2 pi f × L, the inductance.

11. You can see that if the inductive reactance = 2 pi × frequency × inductance, the reactance will double if the frequency doubles, even though we keep the same inductor, and its inductance remains the same. An inductor which gives 100 ohms reactance at 60 Hz will give 1,000 ohms reactance at 600 Hz.

12. What is the reactance of a 265-millihenry inductance at 60 cycles per second? (100 Ω) (265 Ω) (626.5 Ω)

13. Yes. What is the reactance of 265 millihenries at 600 Hz? (1000 Ω) (2,650 Ω) (6,265 Ω)

14. Yes. What is the reactance of 1 henry at 1 cycle per second? (1 ohm) (2.65 Ω) (6.28 Ω)

15. Right. In a DC circuit, the power used is volts × amperes. In an AC circuit, the power used in a pure resistance is RMS volts × amps, too, but not in a reactive circuit. In an inductance, the alternating current is used to magnetize the field and to reverse its magnetism, and if we could have a pure inductance, absolutely no power is used.

16. This must sound strange that, for example, we could connect a high quality 265-millihenry inductor to a 120-volt 60-hertz power outlet, and 1.2 amps would flow through the 100 ohms of reactance which the inductor has at 60 hertz. But it would use virtually no power!

17. This is because for the first part of each of the two alternations of each cycle, the inductor uses energy to establish a magnetic field, and for the last part of the half-cycle, the collapse of the field returns the same power back to the power source.

18. Remember, if the circuit had only inductance and no resistance, the current would be 90° out-of-phase with the voltage; that is, it would lag the applied voltage by 90°, and lead the back voltage by 90°. No "true power" would be used. There would be some apparent power, some "volt-amps" flowing, but no net power would be used up.

19. In an AC circuit containing only resistance, how are voltage, current, and power related? [current and voltage in phase; power is (volts)(amps)] [current lags applied voltage 90 degrees; no power used]

20. In an AC circuit containing only inductance, how are voltage, current, and power related? [current and voltage in phase; power is (volts)(amps)] [current lags applied voltage 90 degrees; no power used]

21. Of course, every real inductor has at least some small resistance, because it must be wound with wire that has a little resistance. In a high-quality inductor, the inductive reactance at the frequencies for which it's designed is very much greater than the internal resistance, but there are often external resistances in connecting wires, connections, and the like which limit current flow. In any case, for analysis, the internal resistance is shown as if it were a lumped resistor

outside the inductor and in series with it.

22. When resistance and inductive reactance occur in series, or internally in an inductor and considered in series, the current lags the applied voltage, but not quite by 90°. In this circuit, the current is shown lagging by only 60°, due to the resistance. If this were entirely due to an inductor's internal resistance, it would be a poor quality inductor.

23. This vector diagram shows the in-phase resistive component of the current, and also the applied voltage, are directed horizontally to the right, at the beginning or zero-degree angle. The inductive reactance voltage component is 90° from it, and the vectorially combined voltage E_o is at 60°. With respect to the applied voltage, what is the current phase angle? (I_o leads E_o by 60°) (I_o lags E_o by 60°) (I_o lags E_o by 90°)

24. Yes. If the applied voltage is, say, 100 volts, the voltage drop across the resistance is the cosine of $60^{\circ} \times 100$, or 50 volts. The voltage drop vector component across the inductor is the sine of $60^{\circ} \times 100$, or 86.6 volts. Push the middle button.

25. We know, from the Pythagorean Theorem, that the square root of the sum of the squares of the sides is the hypotenuse, so the square root of the sum of the squares of the sine and cosine is one, and the square root of the sum of the squares of the resistive and reactive voltage components is the applied voltage.

26. If you have a circuit with 50 volts resistive voltage component and 86.6 reactive voltage component, what is the applied voltage? (86.6 volts) (100 volts) (136.6 volts)

27. There is another word besides "resistance" and "reactance" for a quality which opposes or limits electrical current. This is "impedance." This sounds reasonable, since "impede" means to oppose or limit. Impedance is the combined opposition to the flow of alternating current in a circuit which contains both resistance and reactance.

28. How would you briefly describe "impedance?" (combination of resistance and reactance) (quality which increases current in semiconductors)

29. We use the letter R for resistance and X for reactance. To represent impedance, we use Z. In what kind of circuits does impedance occur? (AC) (DC)

30. When a resistance and an inductive reactance are combined in series, they add vectorially. A 30-ohm resistance in series with a 40-ohm inductive reactance gives a 50-ohm impedance.

31. What is the combined impedance of a 50-ohm resistance and an 86.6-ohm reactance? (100 ohms impedance) (136.6 ohms impedance)

32. Yes, since the effect of resistance and reactance is always 90° apart, their vector sum is always the square root of the sum of their squares. Not every pair of vectors, of course, are 90° apart, but resistive and reactive effects in a series circuit always are.

33. If you start with an impedance of, say, 100 ohms, and you found the current was lagging the voltage by 45°, you would know that both the resistive component and the inductive reac-

tance component were 70.7 ohms. At 45°, both the sine and cosine equal .707.

34. The value of the cosine of the current phase angle is called the "power factor." The power factor of a circuit in which the current is entirely in phase with the applied voltage is one, or 100%. The power factor of a circuit with its current lagging 45° is 70.7%. What is the power factor of a circuit with a 60° lagging phase angle? (50%) (70%) (90%)

35. What is the power factor of a circuit with theoretically perfect inductance and no resistance? (0%) (100%)

36. If you had an AC circuit in which you measured 1,000 volt-amps, for example, 100 volts and 10 amps, and you found it had a 60 degree phase angle between voltage and current, it had a 50% power factor. How many watts of power was being consumed? (500) (600) (1,000)

37. How can you find the power factor of a circuit? (Take the square root of the power in hertz.) (Factor the sum of the series voltages.) (Find the cosine of the phase angle.)

38. What's the impedance of a series circuit with 3-ohms resistance and 4-ohms reactance? (3-ohms impedance) (4-ohms impedance) (5-ohms impedance)

39. Right. And for now, we won't bother with the combination of reactance and resistance in parallel. Remember, in a series circuit, the current is common to all elements; it's the same current everywhere you measure it, because there is only one current in the circuit. But there may be several voltages, and they may not add up arithmetically. In this case, you have to do it vectorially.

40. All of these relationships are based on sine wave AC voltages, and "linear" elements which act the same at all voltages being considered without excessive saturation or other odd effects. It will help if you review these relationships again.

Capacitors and Capacitance

1. A capacitor is a reactive component which is very commonly used in electronics, even more commonly than an inductor, although not as often as a resistor. It has properties which are in some ways just the inverse of an inductor, and which are quite different from a resistor.

2. You may remember that an inductor stores energy in a magnetic field. A capacitor, however, stores energy in an electrostatic field. The larger the capacitance of a capacitor, the more energy it can store at a certain voltage.

3. The capacitor is composed of two surfaces called plates. These plates are separated by air, or a vacuum, or some other substance called a "dielectric." This arrangement resembles the schematic symbol for a capacitor, shown here.

4. In an earlier program, you learned about voltage and electrostatic energy. This energy is found in the electrons that are stored in objects when they have become charged. You know that when a difference in polarity exists between two connected objects, the negatively-charged electrons will flow, or attempt to flow through the conductor.

5. This is what happens in a capacitor. When a voltage is applied to the two plates, an electrostatic field is established. The electrons obtain energy and attempt to move toward the positive plate. If they are bound in atomic orbitals, they are not free to move. The only result is the electrons continue to store energy until the energy applied by voltage and the stored energy are equal. When this happens, the capacitor is said to be "charged." When charged, a capacitor opposes any further voltage.

6. How does a capacitor store electric energy? (in a magnetic field) (in an elastic membrance) (in an electrostatic field)

7. Capacitors are designed to work at a specific voltage. If the rated voltage level is exceeded, the electrons will break through the dielectric because of the large force being placed on them. This could cause a capacitor dielectric to break down and short across, with an arc or a spark which could damage it. It is for this reason that capacitors are clearly rated with working voltage, or maximum voltage, or both.

8. A capacitor is made of two closely spaced plates with relatively large surface area, separated by something. What is it called? (separatance) (capacitation) (dielectric)

9. Right. Different dielectric materials affect the amount of capacitance of a capacitor. If you placed flint glass between the plates of a given capacitor, instead of air or a vacuum, you would increase the capacitance nearly tenfold. Paraffin paper would give 3½ times more than air, mica 3 to 6 times, and rubber, up to 35 times as much. Since air and a vacuum have nearly the same effect, their "dielectric constant" is established to be 1 and most

of the other materials have higher values.

10. A century ago, the English physicist Michael Faraday developed a number of basic relationships in static electricity. Because of this, the unit of capacitance is called a "farad." A capacitor has one farad of capacitance when an applied voltage change of one volt change per second causes a charging current of one ampere to flow. Thus, capacitance in farads is in units of amps-per-volt change per second.

11. What is the electrical unit ratio equivalent of the farad, the unit of capacitance? (amp/volt/second) (ohm/second/henry)

12. We may also say that one farad will store one coulomb of electrical charge when connected across one volt, or Q (charge in coulombs) equals farads times volts. You could store one-thousandth of a coulomb, for example, if you connected one thousand volts to one-millionth of a farad. This is not a lot of charge, but it would make quite a spark.

13. And a millionth of a farad is not a lot of capacitance, but it is a practical amount, far more common than a farad, so the unit "microfarad" is most widely used. In fact, a millionth of a microfarad, called a picofarad, is a useful unit, too.

14. How much charge is stored in a 500-microfarad capacitor at 200 volts? (.0001 coulomb) (.1 coulomb) (1,000 coulombs)

15. While the charge depends on the voltage and capacitance, and the capacitance can be found by measuring the charge and voltage, the capacitance is actually determined by three factors: the area of the plates, the space between them, and the dielectric constant. This is expressed in the formula "$c = .225 \times (\frac{k \times a}{d})$. C is the capacitance in picofarads and k is the dielectric constant. A and d are the cross-sectional area of the plates and the distance between them, respectively. A and d are expressed in inches.

16. The capacitance of an air-dielectric capacitor with 2 plates of 1 square inch size, 1 inch apart, is .225 picofarad. If they're one square centimeter, 1 centimeter apart, it would be only .088 picofarad. If you made a capacitor with plates of 100 square inches, just .01 inch apart, you'd have 2,250 picofarads, or .00225 microfarad.

17. It's common to make fixed value or variable capacitors with multiple plates in layers so that each plate builds up a charge on each of its sides (except the outer layers, of course) to nearly double the compactness of a given capacitance. Also, it is usual to employ various dielectric materials which also have useful mechanical and insulation properties to make practical capacitors.

18. What would the capacitance be in picofarads of a capacitor with 400 square inches of effective interplate area, separated by .009 of an inch of dielectric having a dielectric constant of 10? (1 picofarad) (.229 picofarad) (.57 picofarad)

19. Yes. You've learned that the quantity of electrical charge in coulombs is equal to the capacitance × the voltage. You can see that it requires more capacitance to store the same charge in a low voltage capacitor and less capacitance for a high voltage capacitor. Even though capacitance

can be increased by reducing the distance between the plates, the voltage rating before breakdown of the dielectric is also reduced. This places a limit on how close the plates can be brought together. But as you increase the dielectric thickness between plates in order to raise the voltage rating, the capacitance is reduced.

20. Two capacitors will store the same amount of charge. One capacitor is rated at .1 microfarad at 500 volts. The other is rated at .25 microfarad. What do you think its voltage rating might be? (20 volts) (200 volts) (2,000 volts)

21. Some capacitors indicate a "maximum voltage" and a "working voltage." Since the peak voltage in many circuits may be 50% higher than the effective or "working" voltage, it is a good idea to allow for this in selecting capacitors by voltage rating.

22. What does a capacitor do in an electric or electronic circuit? You recall that an inductor tends to oppose a change in the current flowing in a circuit. When an inductor has an increased voltage applied across it, for an instant it develops a back voltage which opposes the current increase, and only after a delay of a fraction of a second does the current increase toward some maximum value. A capacitor is, in a way, the inverse of an inductor. It instantly permits any increase in current, almost like a short circuit for the increase only, since it tends to oppose the change in voltage for an instant.

23. Which is true: inductors oppose a change in current, or capacitors oppose a change in voltage? (Inductors oppose change in current flow.) (Capacitors oppose change in voltage.) (Both are true.)

24. Right. It's impossible to see electrons moving about, so it's difficult to understand the concept of a surge of current, that is, electrons, into a capacitor which then fills up and stores the energy under a voltage pressure. But that is essentially what happens, and various visible mechanical analogies often help the understanding.

25. For example, let's imagine a tank, say about the size and shape of a quart can of oil with a small pipe or tube at the top and at the bottom, and a rubber membrane or diaphragm stretched across the center of the tank. It's clear that no fluid can go through the tank. Well, no current can really flow through a capacitor either. If there were a sudden pressure differential in the tank, would there be some flow for an instant? (yes) (no)

26. Yes, there would be flow for an instant, depending on the capacity of the tank and the resistance of the pipes or valves. But it isn't true flow in the sense that the fluid which goes in is the fluid that is forced out. Instead, fluid going in will push against the bottom of the diaphragm. The diaphragm then pushes against the fluid above it, forcing fluid out. Eventually, the pressure across the rubber membrane would be the same as the applied pressure, unless, of course, the pressure continued to change back and forth so rapidly that some of the pressure remained across the pipe and valve or other resistances.

27. Once the tank diaphragm has been stretched enough to offset any steady pressure, any apparent flow stops. If there were a bypass pipe and valve connecting the top to the bottom of

the tank, however, this pressure could be shorted out by opening this bypass, and the tank differential pressure would drop to zero.

28. The same sort of thing happens in a capacitor. The battery places a charge on the 2 plates causing the electrons to flow. Electrons are attracted across to the positive plate initially, but are slowed down by the dielectric. Although they are not moving, they store up energy until the voltage pressure applied equals the stored energy. There is no net direct current flow, therefore, except for a brief charging current and surges of voltage back and forth.

29. What electrical phenomenon is employed in a capacitor? (creation of an electrostatic field between 2 plates) (surge of a potential hydraulic pressure field)

30. The capacitor will hold its charge when the voltage is switched off. Charge will leak off the capacitor though. The capacitor can be discharged, however, when the second circuit is connected to allow the pressure to be dispersed.

31. In this circuit, we can see that when the switch is in the upper position, the capacitor will charge up the battery voltage. When it's in the lower position, the capacitor will be discharged. What happens in the middle position? (oscillation) (Nothing, except that if the capacitor is charged, the charge might leak off.)

32. In this circuit, when the switch is connected to the battery, the full DC voltage is across both resistor and capacitor. If the capacitor has been discharged, so the voltage across it is zero at the moment the batter is connected, the voltage across the resistor is also the full battery voltage. As the charge builds up on the capacitor, the voltage rises across it while the voltage drops across the resistor. Eventually, all the voltage is across the capacitor. Since no current is flowing, there's no voltage at all across the resistor.

33. The graph of the current across the capacitor is the same sort of exponential curve as the voltage curve across an inductor. The reverse curve occurs when the switch is dropped to discharge the capacitor through the resistor. The voltage discharge curve across a capacitor is again similar to the discharge current curve through an inductor.

34. A capacitor in series with a resistor has a fixed "time constant." The time constant is the time required to charge (or discharge) the capacitor to 63% of its final voltage. The time constant in seconds equals the resistance in ohms times the capacitance in farads. $T = R \times C$. How long would it take to charge a 3-farad capacitor, in series with a 2-ohm resistor, up to 63 volts, if you applied 100 volts? (2 seconds) (3 seconds) (6 seconds)

35. Right. Since capacitors are often rated in microfarads, what would the time constant be of a 3-microfarad capacitor in series with a 2-megohm resistor? (2 seconds) (3 seconds) (6 seconds)

36. Right. And a 3-picofarad capacitor would charge to 63% through a 2-megohm resistor in 6-microseconds. You may be interested in more than the 63% level. For example, the voltage will go about 21% of the way in about $\frac{1}{3}$ of the RC time constant. And in 3 time constants, it will achieve about 95% of its final value. When discharging, this means, of course, dropping to 5% of its original value.

BASIC ELECTRICITY Reference Folder Pe 15

Capacitive Reactance

1. In the last program you learned that when a DC voltage is connected to a capacitor, current flows for just a short time, then comes to a stop, as the voltage across the capacitor reaches the applied voltage.

2. The reaction of a capacitor when it is connected to an AC voltage, however, affects every alternation of the voltage. Its effect is a continuous charging and discharging of the electrostatic field between its plates. The function of the capacitor, you will recall, is to oppose the rapid change in voltage across it, by supplying current until it is discharged, and accepting current until it is charged.

3. If an AC voltage applied to a capacitor is in a sine wave, or sinusoidal, the current is a sine wave too. And although it may at first be difficult to understand, the current actually leads the applied voltage by 90°. You might think that since current flow is conceived to be the result of voltage pressure, it's impossible to have current actually flowing prior to the existence of the voltage which causes it. In practical circuits, however, this occurs. Why? (There is always some series resistance which limits voltage.) (It's the mystical nature of electronic circuits.)

4. Yes, a discharged capacitor's tendency to draw large current when a DC voltage is applied, or an AC voltage increases from zero,causes most of the voltage to appear in other elements of any circuit, like resistors. If a sine-wave voltage is applied, the current is maximum as the voltage crosses zero, and a quarter-cycle or 90° later, the capacitor voltage is greatest as its current is zero. What result does this have on the current-to-voltage phase angle of a capacitor? (The current leads the applied voltage by 90°.) (The current is in phase with voltage.) (The current lags applied voltage by 90°.)

5. Yes. A capacitor of a certain capacitance will draw an amount of current in an AC circuit which depends on the voltage value and on its frequency. The higher the voltage, the higher the current, of course. And because the current also depends on the rate-of-change of the voltage, a voltage at a higher frequency will cause more AC current to flow through a capacitor than at a lower frequency.

6. In fact, the current in amperes through a capacitor is just the product of 2 pi × the frequency × its capacitance × the applied voltage. The current through a 10-microfarad capacitor, from 100 volts, at 1000 Hz, would be 6.28 amps.

7. What would the AC current be, through a 20-microfarad capacitor, at 100 volts, and 60 hertz? (.024 amp) (.75 amp) (6.28 amps)

8. Correct. We don't always work directly with AC currents, but in circuit analysis we usually combine reactances, resistances or impedances. For capacitors, the tendency to

oppose or limit current is also called "reactance" as is the similar limiting tendency of inductors, although it is a very different kind. You should remember to say "capacitive reactance" or "inductive reactance," when the difference is important.

9. What would you suppose is the term used for the combination of capacitive reactance with resistance? (reluctance) (inductance) (impedance)

10. Right. You've already learned that the current = 2 pi fCE; 2 pi × hertz, farads, and volts. The current-limiting tendency of a capacitor, or capacitive reactance, is the ratio of voltage divided by current, so it equals $\frac{E}{2 \text{ pi } fCE}$ or after cancelling the E's, just $\frac{1}{2 \text{ pi } fC}$.

11. What is the capacitive reactance X_c of a 100-microfarad capacitor to an AC sine wave voltage at 60 hertz? (1.667 ohms) (26.52 ohms) (377 ohms)

12. Which of these is the formula for capacitive reactance? ($X = 2 \text{ pi } fL$) ($X = \frac{1}{2 \text{ pi } fC}$) ($X = \frac{IE}{fC}$)

13. There are several models which physicists use to explain in visual terms the action of electrons in orbits within atoms on electrostatically-charged surfaces. They may be said, for example, to have distorted orbits, and electrons making up continuous current flow may be considered to be "free electrons" which move from atom to atom.

14. In the fluid analogy described in the previous program, the rubber membrane or diaphragm was stretched or displaced, and allowed some limited movement of the fluid, depending on the strength of the rubber membrane and the fluid pressure. But no continuous flow of fluid was possible, of course, as long as the membrane was intact.

15. When the electrons are drawn toward the positive plate, they displace the electrons ahead of them while electrons are drawn behind them. To an observer, who cannot see this happening, it appears that some current is flowing. But it isn't a true conducted current flow. Instead, it is a displacement type of current.

16. Electrons, moving only back and forth in a soldering iron heating element can cause heat, somewhat like your rubbing 2 pieces of wood back and forth. To use energy, we must be sure of one thing, however. What is it? (that pressure and motion are together or in phase) (that the energy is lifted away as you move it)

17. In a capacitor, the current leads the voltage by 90°, so no power is used. Another way of saying this is that the voltage buildup is delayed, so that the voltage is forced to lag the current by 90°. But since it is more consistent to think of current as a result of applied voltage, we say it leads the voltage across the capacitors.

18. In the part of a circuit which contains a capacitor only, is there any net power consumed? (yes) (no)

19. Right. No power is consumed in a pure capacitor as in a pure inductance, since the current and voltage are always exactly "out of phase," or 90° from each other, and the energy absorbed temporarily by the reactive element is returned to the circuit during the following quarter-cycle,

or half-alternation.

20. In a discharged capacitor there is theoretically no tendency to limit the charging current, except the rate at which the applied voltage is changing. This is maximum in a sine wave as the voltage crosses zero, so at that point, where we start here at the left, the charging current is maximum.

21. As the voltage across the capacitor rises, and follows the sine curve with a reduced rate of voltage change, the current, which is proportional to this rate of voltage change, drops, finally going to zero as the voltage reaches maximum. What is the rate of change of the voltage when it is at its maximum value? (zero rate of change) (120 VAC) (maximum rate of change)

22. Yes. Then, just as the voltage starts reducing, the current, which has dropped to zero, reverses and increases, in the opposite direction. In this half alternation, the energy or power stored in the capacitor is actually given up, back into the rest of the circuit.

23. We might say that the storage of energy in a capacitor is like which of these? (in a spring, or rubber band) (dragging a weight on a rough surface)

24. Another characteristic of a reactive circuit is its reactive quality, symbolized by the letter Q. The quality, or Q, or a reactive element or circuit is the ratio of its reactance to its resistance components. The less resistance in the reactor, the greater the Q, or reactive quality index. You may remember that the resistance component was equal to the sine of the phase angle, while the reactance component equalled the cosine. Q is equal to the tangent of the phase angle.

25. Of course, we can never have an entire circuit which has zero power factor, or purely capacitive reactance, but many high quality capacitors have a very high Q, or quality rating. Capacitors generally have a higher electrical Q rating than inductors, since it is physically and mechanically easier to attain.

26. A capacitor is always used in a circuit with some resistance, so its reactance is combined with resistance to present what kind of current limitation? (impudence) (impedance) (impatience)

27. Yes. The resulting impedance is made up of capacitive reactance and resistance which act at right angles, or 90° out of phase, so this effect must be vectorially added when they are connected in series.

28. To add 2 vector quantities at right angles from each other is quite simple; you merely use the Pythagorean Theorem and find the square root of the sum of their squares. The impedance Z of a series capacitor reactance X_c and a resistance R is the square root of $R^2 + X_c^2$. How does this compare with the method of finding the series impedance of a resistor with an inductor? (quite different) (essentially the same)

29. What is the impedance of 40 ohms capacitive reactance and 30 ohms resistance in series? (30 ohms at 0 degrees) (50 ohms at 53 degrees) (70 ohms at 90 degrees)

30. Yes. The phase angle is the angle whose tangent is the reactance divided by the resistance. For example, the phase angle for 100 ohms reactance in series with a 100 ohms resistance would 45°.

31. What's the phase angle of 86.6 ohms of capacitive reactance in series with a 50-ohm resistor? (30 degrees) (45 degrees) (60 degrees)

32. Right. Let's assume we have a 40-microfarad capacitor in series with a 20-ohm resistor, and we connect them across 120 volts at 100 cycles. First, what is the reactance of the capacitor? [$X_c = \frac{1}{2 \text{ pi } fC}$; $X_c = \frac{1}{(6.28)(100)(40 \times 10^{-6})}$] [X_c = 2 pi fC; X_c = (6.28)(100)(40)]

33. Correct. What is the approximate value of $\frac{1}{6.28 \times 100 \times 40 \times 10^{-6}}$? (40) (168.2) (412)

34. Yes. Here is the vector diagram of the capacitor and resistor in series. How do we find the phase angle of 40-ohms reactance and 20-ohms resistance? (the sine of 60 ohms) (the angle whose tangent is $\frac{40}{20}$, 63.4°)

35. Right. How do we find the total impedance? (only by $\sqrt{40^2 + 20^2}$) (only by $\frac{40}{\sin 64.3^\circ}$ or $\frac{20}{\cos 64.3^\circ}$) (any way; it's 44.7 ohms)

36. How do we find the current? ($I = \frac{E}{Z} = \frac{120}{44.7}$ = 2.68 amps) ($I = \frac{E}{R} = \frac{120}{20}$ = 6 amps) ($I = \frac{E}{X} = \frac{120}{40}$ = 3 amps)

37. How do we find the power factor? (PF = Cos 6.43° = .446) (pf = sin 64.3° = .894)

38. Yes, we might call it a 44.6% power factor, and if we multiplied it times the 120 volts times 2.68 amps, we would get the actual power used. What is it? [(120 V)(2.68 amps)(.446) = 143.4 watts] [(120 V)(2.68 amps)(44.6%) = 2,872 watts]

39. Yes. The so-called "apparent power," or volt-amperage, is just 120 volts times 2.68 amps or 321.6 volt-amps, prior to applying the power factor. What would be another way of calculating power? [$W = I^2R = (2.68^2)(20)$ = 143.4 watts] [W = ER = (120)(20) 240 watts]

40. Yes. It will help to repeat this program and to do some practice with these formulas. In the next program you will learn about some peculiar effects when capacitors and inductors get together.

BASIC ELECTRICITY Reference Folder Pe 16

Analyzing Reactive Circuits

1. In the last 4 programs, you have learned about inductors and capacitors and about some of the ways these electrical components function in electrical circuits in combination with resistors. Inductors or capacitors are widely used in electronic circuits in combination with resistors to discriminate against or to favor low frequencies, direct current, or higher frequencies.

2. In some circuits, inductors and capacitors are used together, along with some resistance, which is intentionally or unavoidably present. You have learned that inductance and capacitance are in some respects the inverse of each other and you will not be surprised to learn that they tend to cancel out each other's effect in a circuit with some interesting results.

3. For example, in series AC circuit containing resistance, capacitance and inductance, the current, of course, is the same through all 3 elements. The voltages, you have learned, are "in phase" across the resistor and are 90° leading and lagging the current respectively, across the inductor and capacitor. For some purposes it is convenient to speak of current lagging and leading the voltage, but in a multi-element series circuit the common factor is the current, so we reverse the leading and lagging descriptions when we refer to voltages across series elements.

4. Before we go on, let's see if you can guess the phase relationship between the voltage across a capacitor compared to the voltage across an inductor in a series resistor-capacitor-inductor circuit. (in phase) (64.3° out-of-phase) (180° out-of-phase)

5. Right. This means they tend to cancel each other's effect. Don't forget that some of the resistance, which we show separately, is in fact distributed in or through the inductor or capacitance, but for ease of analysis, it is considered separately.

6. When a series resistor-inductance capacitance, (which we'll call series RLC circuit) has, at a given frequency, a greater inductive reactance than its capacitive reactance, it has an overall effect of merely a resistance-inductance, or RL, circuit, at that frequency. Some of the inductive reactance has merely been cancelled out by whatever capacitive reactance is developed at that frequency by the capacitor in the circuit.

7. For example, at a certain frequency, a series RLC circuit has a resistance of 100 ohms, a capacitive reactance of 300 ohms, and an inductive reactance of 400 ohms. What is its net impedance? (141.4 ohms) (400 ohms) (800 ohms)

8. Yes, it has a resistance component of 100 ohms, and an inductive reactance component of only 100 ohms, after 300 of its 400-ohm inductive reactance has been cancelled by the capacitive reactance. And the 100-ohms resistance and the 100-ohms net inductive reactance add vectorially to a sum of 141.4 ohms, at a 45° overall phase angle, inductive.

9. Remember, the current leads the voltage across a capacitor by 90^{o}, and the current lags the voltage across an inductor by 90^{o}. This means the voltages have what relationships with respect to the single common current in a series circuit of these elements? (Voltage leads current in capacitor; voltage lags current in inductor.) (Voltage lags current in capacitor; voltage leads current in inductor.)

10. Right. This series circuit has an inductive reactance of 200 ohms and a capacitive reactance of 250 ohms, both in a series circuit with a 300-ohm resistor. What is the effective impedance? (304 ohms, impedance; slightly capacitively reactive) (350 ohms) (550 ohms)

11. Yes, and the phase angle has a tangent of 50 ohms net capacitive reactance divided by 300 ohms resistance, or about 10^{o}. What do you think is the power factor of such a circuit? (10%) (50%) (99%)

12. Let's assume that we have a series circuit with 800 ohms inductive reactance, 700 ohms capacitive reactance, and 100 ohms resistance. It would appear to be a 141.4-ohm vector impedance with 100 ohms inductive reactance and 100 ohms resistance, and a 45^{o} phase angle for the current relative to the overall applied voltage. To simplify matters, say we have 141.4 volts applied to the ends of this series circuit. What is the current through it? (1 amp AC) (141.4 amps AC) (141.4 amps)

13. Yes. 141 volts, across 141 ohms would result in a 1-amp series current. But since this is an RLC circuit, this 1-amp current will generate opposing voltages on the inductor and capacitor. What will they be? [80 volts (L), 70 volts (C)] [141.4 volts on each] [800 volts (L), 700 volts (C)]

14. Right. Let's hope that the insulation on the coil wire of the inductor, and the voltage breakdown level on the dielectric of the capacitor, are sufficient to avoid damage to them. When the quality Q of the circuit is high, and the reactances are high relative to the resistance, while cancelling each other, high voltages can appear in such a series circuit. This is a very useful relationship for what kind of system? (electric hair dryer) (ignition system in automobile)

15. Right. The greatest effect of this sort, of course, is at the point where the alternating current frequency causes a selected inductance and capacitor combination to have identical magnitude and opposite phase reactances. This is the point at which they are tuned to "resonance." A resonance series RLC circuit therefore has a purely resistive impedance, and the current equals the applied voltage divided by the resistance. The voltages across the inductor and capacitor, which are equal and opposite, equal their reactance times this current.

16. When is a circuit "series resonant"? (when X_c and X_L are equal and opposite) (when its frequency is tuned to the impedance of the hertz)

17. Yes. Since $X_L = 2 \text{ pi } fL$ and $X_c = \frac{1}{2 \text{ pi } fC}$, and they are equal, at resonance, we can say that $2 \text{ pi } fL = \frac{1}{2 \text{ pi } fC}$. Multiply both sides of this equation by f and you get $f^2 \times 2 \text{ pi } L = \frac{1}{2 \text{ pi } C}$. Divide both sides by 2 pi L and you get $f^2 = \frac{1}{(2 \text{ pi})^2 LC}$. Take the square root of both sides, and what do you get? ($f = \frac{1}{2 \text{ pi } LC}$) ($f = \text{pi } LC$)

18. Yes, this is the resonance frequency. Say L is 1 henry, and C is 1 microfarad or 10^{-6} farad. The square root of LC is thus 10^{-3}, and this makes $f = \frac{1000}{6.28}$, or about what frequency? (6.28 hertz) (160 hertz) (1,000 hertz)

19. Yes, 1 henry and 1 microfarad would appear to resonate at about 160 cycles per second. One henry and 1 farad would resonate at only about .16 cycles per second. If we wish to resonate at 60 hertz, we would need nearly 2 microfarads and 2 henries.

20, If we wished to resonate at, say, 1,000 hertz with 1 henry, we'd only need .025 microfarad. It probably would be a better balance to use .1 henry, and .25 microfarad.

21. What is the resonance frequency of 100 millihenries and 1 microfarad? [$F = \frac{1}{2\ \text{pi}\ \sqrt{(.1)(1)10^{-6}}} = \frac{10^3}{(6.28)(.316)} = 504$] (62 hertz) (504 hertz) (3,160 hertz)

22. If you are able to control and vary the frequency of the applied voltage by controlling the speed of an AC rotary alternator, or by tuning an electronic AC generator, you could set the frequency at some point higher or lower than at resonance.

23. At a frequency higher than resonance, which has the higher reactance? (inductance) (resistance) (capacitance)

24. At a frequency lower than resonance, which has the higher reactance? (inductance) (resistance) (capacitance)

25. At a frequency slightly higher than resonance, how would you describe the impedance of a series RLC circuit? (763.25 ohms) (slightly inductive) (403.68 hertz)

26. At a frequency lower than resonance, what kind of series RLC circuit will you have? (capacitive) (resistive) (inductive)

27. Circuits in which the capacitor and the inductor are in parallel, are similar in some ways to series resonance circuits; yet in another way, appear the inverse. The frequency at which the parallel circuit resonates is the same as for a series circuit; it's the frequency at which the reactances are equal in amount and opposite in phase.

28. But although the impedance of each reactive element of a parallel resonance circuit at the resonance frequency may be only a few hundred ohms separately, when they are combined, the effective impedance may appear to be thousands of ohms. This is why.

29. If there is little internal resistance in the capacitor or inductor, then the quarter-cycle period when there is a tendency of the inductor to return stored energy from its magnetic field almost exactly coincides with the quarter-cycle when the capacitor is accepting and storing energy.

30. These relatively large amounts of power are kept oscillating between the two components by only a relatively small amount of energy input from the applied voltage. This action results in an apparent high impedance to the input to the parallel circuit, and a low current flow from the voltage source.

31. In a series RLC circuit, the out-of-phase reactances of capacitor and inductance tend to cancel out impedance and lower it. What occurs in a parallel capacitor-inductor, or LC, circuit at or near resonance? (The apparent parallel impedance is quite high.) (The impedance is unchanged.) (The impedance is lowered.)

32. Yes. A parallel resonance circuit is sometimes called a "tank" circuit, and is sometimes enclosed in a shield. When it is exactly tuned to the frequency of the applied voltage, its impedance is purely resistive, and appears high. The quality factor, or Q, of a parallel resonance circuit is generally limited by the inductor resistance, since it is easier and less expensive to make capacitors with low effective internal resistance than inductors.

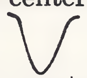
33. This is one way of showing the vector diagram of the voltages and currents in the 2 branches of a parallel resonance circuit. The net current is in phase with the applied voltage, shown horizontally to the right. Look this over before you go on.

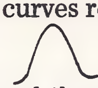
34. Remember that the current, I, leads or precedes the voltage, E, in a capacitor. This is opposite to what happens in an inductor. In an inductor, the voltage E leads the current I.

35. In what kind of component does the current lag the voltage? (capacitor) (resistor) (inductor)

36. Don't forget, the impedance of a series circuit at resonance is low, so the current is high for a low applied voltage. The reverse is true of a tank circuit, so sometimes resonance in a parallel circuit is called "anti-resonance." Study this, then push the center button to go on.

37. If the resonance frequency is at the center, which of these curves represents the impedance of a parallel-resonance circuit?





38. What is the phase angle between the reactance of a circuit and the resistance when they are in series? (0 degrees) (45 degrees) (90 degrees)

39. In a parallel resonance circuit, you must remember the high currents circulating in the capacitor and inductor. In a series-resonance circuit, what must you be aware of? (high voltages across components) (high currents through components) (high impedances of components)

40. Yes. In this series of programs, you have learned basic electrical relationships which apply to all circuits whether they are intended for electrical power, or electronic control or communications. In another series, you can learn about specific electronic circuits and applications. We wish you the best in your studies!

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